ABSTRACT

DYSART, NIKHOL ELIZABETH. Effect of Birth Weight and Human Socialization on the Reproductive Performance of Adult A.I. Boars. (Under the direction of Dr. William L. Flowers).

The objective of this study was to examine the effect of birth weight and socialization prior to puberty on reproductive performance of A.I. boars. Twenty boars were randomly allocated to a factorial arrangement of treatments including birth weight (BW: High or Low) and socialization to humans (Socialized or Unsocialized). Boars were trained for semen collection at 150 days of age and then collected once weekly for 27 consecutive weeks. Socialization improved the training success ($p \leq 0.05$) and reduced the mounting time ($p = 0.007$) of Low birth weight boars, but had no effect on these same parameters in High birth weight boars ($p \geq 0.21$). Both birth weight ($p < 0.001$) and socialization ($p < 0.001$) had a positive effect on total sperm per ejaculate. High birth weight boars that were socialized averaged 77.0 ± 2.8 billion compared to 54.1 ± 1.9 billion for their low birth weight, unsocialized counterparts. Semen quality parameters including motility, mobility (CASA analyses) and morphology were not affected by either birth weight ($p \geq 0.15$) or socialization ($p \geq 0.21$). Results from this study indicate that sperm production in adult boars has a positive relationship with birth weight and can be increased further by socialization to humans during their prepubertal development without any detrimental effects on semen quality. In contrast, socialization appeared to enhance libido only in low birth weight boars.

Effect of Birth Weight and Human Socialization on the Reproductive Performance of Adult A.I. Boars

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BIOGRAPHY

Nikhol Dysart was born on October 22, 1990 in Anchorage, Alaska to Joe and Karen Garbacik. She has a twin sister, Stefani and a younger sister, Brianna. She graduated from Jack Britt High School in Fayetteville, North Carolina in 2008.

After graduating from high school, Nikhol attended North Carolina State University where she received her Bachelor of Science in Animal Science and a minor in Wildlife Management in May 2012. In August 2012, she began to pursue her Master of Science in Animal Science under the direction of Dr. William L. Flowers at North Carolina State University.

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LITERATURE REVIEW

Introduction

There are many factors that affect the production of semen. Most of these that are commonly cited affect adult boars once they have already reached puberty and are actively producing sperm (Flowers, 1997). Conversely, limited attention has been given to factors that occur prior to puberty and their effect on adult reproductive performance. The main objective of this literature review is to review what is known about the manner in which management during pubertal development affects adult reproductive characteristics. It will begin with a brief overview of sexual maturation in boars since this is the reproductive process that is being altered. It will conclude with a summary of various aspects of prepubertal management that have been implicated in playing important roles in semen production in adult boars with particular attention devoted to the influence of birth weight and socialization with humans since these were the two main independent variables manipulated in the present study .

Puberty in the Boar:

Puberty can be defined many different ways. However, there are several events that must occur in order for the boar to be considered sexually mature and able to impregnate a female. Boars must produce viable sperm cells and be able to copulate efficiently. While boars do not always mate naturally in the modern swine industry, they must be able to mount and be collected off a dummy sow. When spermatozoa are not formed correctly or they do not have time to mature in the epididymis, they will not properly fertilize ova. Puberty in

boars is not dependent on any one factor. Age, temperature and humidity of the environment, nutrition, housing, and human interactions all play key roles in affecting pubertal development in swine. One does not appear to be more significant than another, but all affect sperm production in some way.

Pubertal Development

Puberty is the process that classifies an animal as "sexually mature" or the animal is able to produce offspring (Gordon, 2004). Animals must reach puberty before they can be introduced into the herd as "breeding animals". Male and female animals usually reach this stage at different ages; swine as a species are no different. Boars usually reach sexual maturity around the age of 6 months old (Gordon, 2004). Some researchers claim an animal is sexually mature and able to sire offspring after the first ejaculate. However, other studies disagree and have reported that spermatozoa from boars at this age are generally immature and contain many cytoplasmic droplets which would prevent them from fertilizing ova (Malmgren, 1998).

The age of puberty in any species of animal is not finite; this is true in swine as well. Every animal is different in when they reach puberty; a study by Wiggins and colleagues (1951) shows that their inbred boars had an average age of 200 days at the onset of puberty and an average weight of 150 pounds. However, their study was also done over two years and showed a difference between years; the boars in 1948 had a younger age at puberty (196 days vs. 205 days) and the weight was larger at the age (166lbs vs. 141lbs). These results show that the boars may have been younger at puberty in 1948 but they also weighed more

than those studied in 1949. Onset of puberty also varies with breed. Meishan pigs have been found to reach puberty at earlier ages, as well as having smaller testicles and slower growth than other breeds or even crossbred pigs (Ford and Wise, 2009). These Meishan boars reached puberty as early as 75 days of age (spermatozoa were found in the seminiferous tubules) but probably needed until atleast 120 days of age to produce normal spermatozoa capable of fertilization. It has been suggested that as the swine industry has made a concerted effort to increase leanness through genetic selection, age at puberty has increased (Gordon, 2004). The rationale behind this argument is that animals with reduced body fat are physiologically less mature than their counterparts with increased body fat since an increase in adipose tissue relative to muscle is a common change that occurs as animals age. It seems reasonable that this would apply to all physiological events including puberty. Whether or not increased selection for lean has delayed puberty in swine is still a topic of much debate within the swine industry.

Sexual Behavior

Sexual behavior is dependent on many factors, including the internal and external environment of the animal (Hemsworth and Tilbrook, 2007). Testicular hormones, as well as others, are important to the expression and continuation of sexual behavior in males. Testosterone is the hormone most closely related with male sexual behavior and this hormone has been widely studied to determine its effects on libido and semen quality (Flowers, 2008). Male animals must have both the tendency or drive (libido) and the ability (competency) to copulate (Hemsworth and Tilbrook, 2007).

Competency to mate can be handled and addressed somewhat in the management practices of the industry. A boar can be trained to mount a dummy sow and taught the proper way to be collected (Hemsworth and Tilbrook, 2007). Libido is much more difficult to manage. It is based on hormone production and without testosterone and other testicular hormones, a boar will never have the urge to mate and thus, have very low libido. Libido is usually measured by the time it takes a boar to notice or interact with the dummy sow and the time after this that it takes him to mount (Katz and McDonald, 1992). This is not a learned behavior, but strictly associated with the individual characteristics of a particular boar. Two boars seldom react the same.

Genetics has been shown to affect sexual behaviors of boars. Libido is heritable and crossbred boars have increased aggressiveness during mating or collection (Flowers, 2008). Duroc boars seem to be less interested in mounting the dummy sow and this could be due to low libido which could, in turn, be the result of low testosterone (Flowers, 2008). Competency, even if an animal is deficient in this aptitude genetically, is somewhat trainable so if problems exist then they are partially correctable. Housing of the boars impacts their competency. If boars were housed without visual or physical contact of others between the ages of three and thirty weeks, then they achieved fewer copulations and had less “courting” behaviors compared with boars housed with other animals (Hemsworth and Tilbrook, 2007). Boars reared together had better response values and more copulations than boars housed separately. This could be due to the way boars “compete” with each other and see other males as a threat, so they try to breed as many females as possible. Alternatively, boars might learn the mechanics of mounting and other mating behaviors including pelvic thrusting,

grunting and salivation from interactions with other animals during this developmental period. Sexual behavior is an important trait for the swine industry and there would be major economical and production implications if a boar does not express them. He would, essentially, be inefficient at breeding and most likely be culled regardless of genetic merit (Hemsworth and Tilbrook, 2007).

Spermatogenesis

Spermatogenesis is the development of spermatozoa in the testes and their subsequent maturation in the epididymi; once the animal has reached puberty, it is a continuous process. Each spermatozoon goes through three stages of development in the testes before entering the epididymi for final maturation. Only then are the sperm cells able to exit the male and produce viable offspring (Wodsedalek, 1913).

The first stage is spermatocytogenesis or mitosis (Franca et al., 2005). Mitosis is the division of cells and involves the stem cells in the testes, also known as Type A spermatogonia, dividing to form Type B spermatogonia. This division allows all of the other processes to occur and provides the cells that will continue along the developmental path to become spermatozoa (Franca et al., 2005). The second stage is short chronologically and involves the division of spermatogonia into spermatids. The spermatogonia go from being Type B to mitotically dividing to become primary spermatocytes, with round heads. These enter the first meiosis and double their DNA, leave the basal compartment and reach the luminal compartment. One primary spermatocyte produces two secondary spermatocytes, which then enter the second meiosis. The chromatids of the secondary spermatocytes divide

quickly and two haploid spermatids emerge (Franca et al., 2005). The final stage of spermatogenesis is the metamorphosis of the spermatids into spermatozoa. The shape of the head is elongated; the acrosome is formed; and the flagella becomes mobile (Wodsedalek, 1913). The culmination of these three stages is the production of functional, but infertile sperm cells. The spermatids then enter the epididymi and are transformed into sperm cells. In the process of sperm maturation, the spermatids must enter the head, body and tail of the epidiymis to become fully mature. Once the spermatids leave the testicle and enter the head of the epididymis, proteins are incorporated into the head of the spermatid which are thought to be influential in fertilization (Almeida et al., 2006). The spermatid then enters the body of the epididymis by fluid movement; it is in the body where tail movement function occurs. The spermatids are very concentrated and then travel to the tail where they are stored until ejaculation. They will only fully be able to "swim" when they have left the epididymis and diluted with seminal plasma to travel in the female reproductive system. The entire process takes about 45 days in the boar from the start of mitosis to ejaculation (Franca et al., 2005).

Sertoli cells appear to directly affect sperm production. These "nurse cells" are important in their development and maturation during the three stages associated with spermatogenesis (Flowers, 2008). An increased number of Sertoli cells leads to an increase in total spermatozoa. The number of spermatozoa that each Sertoli cell can support is thought to be determined before birth and there is little evidence that it increases significantly after birth. As a result, an increase in the number of Sertoli cells via mitotic activity is thought to be responsible for quantitative differences in sperm production among adult males. There are two periods of active proliferation of Sertoli cells in boars: one occurs during the three week

period after birth which coincides on most swine farms with lactation and the other is thought to take place between days 28 and 50 of age (Flowers, 2008). Sertoli cell efficiency seems to be the best indicator of spermatogenic success (daily sperm production per gram of testis). Sertoli cell efficiency is species-specific. Each Sertoli cell is able to support a limited number of germ cells which will proliferate into spermatozoa (Almeida et al., 2006). Sperm production has been shown to be directly correlated with testicle size as boars with large testicles produce more spermatozoa than boars with small testicles (Ford and Wise, 2011). Notable differences in testicle size and sperm production are present among different breeds. Many studies show that crossbred boars produce more sperm compared with their purebred counterparts, especially Hampshire and Landrace boars (Flowers, 2008).

Hormones of Spermatogenesis

There are many hormones associated with spermatogenesis. The same hormones that regulate spermatogenesis also affect the sexual behavior of boars creating a correlation between reproductive behaviors and the actual production of sperm. In general, male endocrinology involves secretion of protein hormones in a pulsatile fashion by the hypothalamus and pituitary gland which stimulate production of the steroid hormones in a somewhat continuous pattern by the testes (Hemsworth and Tilbrook, 2007).

Ultimately, spermatogenesis in the boar is initiated and regulated by hormones at the level of the hypothalamus. The hypothalamus releases Gonadotropin Releasing Hormone (GnRH) which is a hormone responsible for inducing the release of Follicle Stimulating Hormone (FSH) and Luteinizing Hormone (LH) from the pituitary gland (Franca et al.,

2005). FSH stimulation in the testes initiates spermatogenesis by stimulating sperm cell mitosis and meiosis. FSH binds directly to receptors on to the surface of Sertoli cells to stimulate these events (Malmgren, 1998). Testosterone is accumulated by Sertoli cells in large amounts in order to produce sperm cells. The main source of testosterone is Leydig cells which are stimulated by LH from the pituitary gland. Anatomically, Leydig cells are adjacent to seminiferous tubules containing Sertoli cells so testosterone acts locally within the testes to stimulate spermatogenesis. It also is secreted into the blood stream to act on other organs such as the secondary sex glands and portions of the brain that are involved in other aspects of male reproductive physiology (Malmgren, 1998).

Several other hormones involved in proper male reproductive functionality include estrogens, dihyrdotestosterone, and oxytocin (Franca et al., 2005). The epididymi, where sperm cells are stored, rely on hormones such as dihyrdotestosterone to regulate the maturation and transportation of the sperm cells. Estrogens and oxytocin work within the seminiferous tubules and accessory sex glands to regulate the volume and composition of seminal plasma (Franca et al., 2005). Oxytocin is particularly important because it causes the sperm cells to move along the tubule and if this movement is delayed or hurried, then the maturity and fertility of sperm cells will be compromised (Malmgren, 1998).

These hormones regulate spermatogenesis and male reproductive physiology, in general, in a coordinated and interactive manner. While testosterone is often considered to be the most important hormone for sperm cell production, fertility, and sexual behavior in boars, its ultimate ability to direct reproductive activity is dependent on other hormones such as FSH, LH, estrogens, and oxytocin. Even if testosterone levels are normal, the fertility of

the animal can be suboptimal if one of these is missing or is not produced at the proper time or in adequate amounts (Franca et al., 2005).

Semen Quality and Quantity

There are many different characteristics of semen that have been studied in an attempt to determine its "viability". Many of these features have been studied in numerous animals and are relatively similar across species. While boar sperm are not exactly the same shape as bull sperm, it is recognized that each must possess a unique conformation and move in a particular pattern to properly fertilize ova (Malmgren, 1998). Fertilization also is dependent on viable sperm reaching ova at the optimal time and penetrating their zonae pellucidae. This cannot occur if the sperm head or acrosome is not properly formed and if the tail is abnormal and does not propel the spermatozoa forward. Finally, spermatozoa in an ejaculate may all be normal in shape and function, but if insufficient numbers are present, then reproductive performance will also be poor. Consequently, both the quantity and quality of semen produced determines the overall fertility of males.

Sperm production varies across breeds (Flowers, 2008) and, as mentioned previously, it has been shown that crossbred swine produce more spermatozoa than their purebred counterparts (Flowers, 2008).While there does not seem to be a clear reason why one breed of swine would produce more spermatozoa than another from an evolutionary perspective, it is important to note that differences do exist. These differences probably are not the result of deliberate genetic selection since the commercial swine industry has really not placed much selection pressure on semen quality or quantity traits in boars (Flowers, 2008). The

production of viable sperm has also been shown to be dependent on testicular size; increased testicle size increases the amount of sperm produced (Flowers, 2008). This is most likely due to an increase in Sertoli cell mitotic activity during sexual maturation which, in turn, results in larger testicles since Sertoli cells are the most numerous cell type found in adult testicles (Flowers, 2008). Likewise, daily sperm production increases as the number of Sertoli cells present increases. Consequently, the positive relationships among testicular weight, Sertoli cell numbers and sperm production appear to have a logical connection from a physiological perspective (Ford and Wise, 2009).

Motility and morphology of spermatozoa are the most common criteria used to assess semen quality. For semen to be of good quality, the majority of sperm in an ejaculate must have good motility and morphology which means that they must move in a straight line at a certain speed and possess certain structural characteristics such as a straight tail and an oval-shaped head with a normal acrosome (Suriyasomboon et al., 2005). When spermatozoa are not formed correctly in the testes (primary defects) or they do not have time to mature in the epididymis (secondary defects), they will not properly fertilize ova and fertility is likely to be decreased (Malmgren, 1998). There is a suggestion that sperm cells with abnormal tails or heads cannot reach the oviduct due to a selection mechanism in the utero-tubal junction of the female (Malmgren, 1998). This has not been proven definitively and there are reports in which dead sperm have been recovered from the oviduct within several hours of insemination. In contrast, when sperm with normal tails and head, but damaged DNA reached the ovum, they penetrated zona pellucida and initiated the zona block which prevented entry of other sperm. However, in these situations fertility was still decreased

because syngamy of the male and female pronuclei did not occur. Consequently, it can be inferred that abnormalities in sperm can occur at many different levels. Some can be identified prior to insemination and fertilization while others can only be assessed by the efficient production of live piglets.

Summary

Spermatogenesis is the process by which sperm cells are made and this must occur in every male animal when reaching puberty. These sperm cells must be properly functioning, as well as properly shaped in order to be viable. Superior semen quality and quantity are essential to fertilization and siring of offspring; just because a boar produces sperm does not mean that he produces viable sperm cells able to fertilize an ovum.

Factors affecting Sperm Production

Age

Many factors attribute to reproductive success in boars (Smital, 2009). Age is an important one and should not be taken lightly in determining the reproductive status of a boar. The general pattern of sperm production in boars is to increase rapidly from six to about thirteen months of age after which it tends to rise gradually or reach a plateau (Flowers, 2008). Consequently, in any study evaluating sperm production among different groups of boars, it is important to begin when boars are 6 months and continue until they have reached their plateau or wait until all boars have matured sufficiently so that their semen production has reached its plateau. If one of these two strategies is not followed, then

sperm production is likely to be confounded with any treatment administered and normal changes that occur over time.

From a practical perspective, boars in the swine industry typically are trained at 6 months of age; enter the stud between seven and nine months of age; and are culled between 24 and 36 months of age (Sonderman and Luebbe, 2008). Consequently, semen production data from boars older than 24 months old is of little practical benefit for the commercial swine industry even if significant differences are observed among various treatments or management strategies.

Temperature and Photoperiod

Seasonal breeders have a decrease in the reproductive activity during nonbreeding seasons (Ford and Wise, 2009). While modern swine are not considered to be seasonal breeders, their original ancestors, wild pigs, definitely were with their non-breeding season occurring during the late Summer and early Fall (Mauget, 1982). Numerous studies have shown that both the quantity and quality of semen decreases in boars exposed to elevated ambient temperatures (Flowers, 1997; Flowers, 2008). Consequently, it is possible that both internal (genetic tendency for seasonality) and external factors (elevated temperatures and decreasing photoperiod) affect reproductive function in boars. When the temperature exceeds 85° F and humidity rises to 85%, there is a negative impact on spermatogenesis if those conditions occur for ten days or more (Sonderman and Luebbe, 2008). A current hypothesis, known as the Bunning Hypothesis, states that there is a critical period in the circadian rhythm in swine and when they are exposed to light during that period, the exposure leads to a

change in their neuroendocrine response (Mahone et al., 1979). Hormone regulation is altered and this may cause decreases in sperm viability, semen volume and testicular firmness. All of these aforementioned changes would act to decrease the reproductively viability of boars.

In the study conducted by Mahone and colleagues (1979), nine littermate pairs of boars were placed in a control or a light group. The light groups were exposed to light for a total of a fifteen hour photoperiod whereas the control group was exposed to normal daylight (9.3 to 12.7 hours). The boars receiving additional exposure to light were heavier at twenty-four weeks of age and had softer testicles, but had higher overall sperm concentration than the control group. There were no differences detected in semen volume or motility (Mahone et al., 1979). In this study, temperature was held constant, so the observed changes were attributed to changes in photoperiod. Nevertheless, there is still some disagreement as to what conditions and through which physiological mechanisms boars respond to changes photoperiods. Other studies have failed to observe photoperiodic responses in boars (Flowers, 1997) and it appears that boar do not experience changes in the photoperiodic hormone, melatonin, in the same way as other livestock species do in response to changes daily light/dark cycles (Brandt and Diekman, 1985).

In contrast, high temperatures also cause a decrease in food consumption and water intake; both of these can inhibit spermatogenesis (Kunavongkrit, 2005) and even when nutritional restriction is not present, they can have direct effect on the hypothalamic-pituitary-testicle axis which results in significant reductions in both semen quality and quantity (Flowers, 1997). The latter appears to happen routinely in swine located in semi-

tropical climates. A study conducted in Thailand showed that high temperatures, associated with longer photoperiods, had detrimental effects on semen quality (Suriyasomboon et al., 2005). This combination of high temperature and long photoperiod reduced the proportion of normal sperm by increasing the frequency of sperm with proximal and distal cytoplasmic droplets (Suriyasomboon et al., 2005). Proximal and distal droplets are interpreted as being indicative of immature sperm with reduced viability (Sancho et al., 2004). This particular study is a good example of the challenges involved with interpreting the effects of photoperiod and temperature on semen production in boars. Even though the photoperiod to which these boars were exposed had 15 hours or more of light, their semen production was suboptimal, presumably due to the elevated ambient temperatures. Consequently, it appears that heat stress has a more profound and significant effect on semen quality and quantity than photoperiod in boars.

Nutrition and Housing

Reproductive functions in prepubertal animals are affected significantly by energy and protein dietary restrictions, whereas, only slight to modest changes are observed in adults (Brown 1994). Extreme restrictions in food and water intake cause permanent damage to gonadal and neural tissues (Brown, 1994). The energy and protein content appear to be the two most important nutrients for pubertal animals and a deficiency in either of these delays onset of puberty, reduces libido, and suppresses testicular function (Brown, 1994). According to N.R.C. requirements set in 1998, developing pigs require 3.3MCal of metabolizable energy and 18% total protein in a 90% dry matter ration.

In contrast, adult boars require 6.530 MCal of metabolizable energy and 13% total protein in a 90% dry matter ration.

It was originally thought that housing did not have much influence on reproduction, unless it is associated with humidity or temperature changes as well (Mahone et al., 1979). Another study in Thailand examined interactions among temperature, humidity and housing (Suriyasomboon et al., 2005). High temperature accompanied by an increase in humidity had detrimental effects on sperm morphology. Three seasons were analyzed in this study to show the varying temperature, photoperiod, and humidity effects (Suriyasomboon et al., 2005). Total sperm production was higher during the winter season and total sperm defects were elevated in the rainy season, when humidity would have been higher (Suriyasomboon et al., 2005). The two housing types differed by the type of cooling system; one was a conventional air system (CONV) barn and the other was an evaporative cooling system (EVAP) barn. The EVAP barn helped reduce seasonal changes and may help stabilize sperm production in the warm, humid months.

However, a recent study examined the effect of housing boars in pens versus crates in a cross-over experimental design (Tosky et al, 2013). Fourteen mature boars were randomly assigned to be housed in crates or pens. Dimensions for the crates and pens were 0.9 m x 2.1 m and 1.8 m x 2.5 m, respectively. After a 2-wk acclimation period, boars were collected weekly for 10 weeks. After this period, the housing environment was switched and boars were collected weekly for a second 10-week period. During the last two weeks of each 10-wk collection period, heterospermic inseminations across treatments were prepared and used to breed sows. Boars housed in pens had increased libido due to shorter reaction times; and

longer collection times compared with those housed in crates. Total sperm per ejaculate was elevated when boars were kept in pens compared with when they were kept in crates. This was due to increased semen volumes. Percentages of motile and morphologically normal spermatozoa were not different. Despite these similarities, regression analyses revealed that for some boars the transition from a crate to a pen had a negative effect on sperm production, while for others being housed in a crate after being in a pen was stimulatory. Relative fertility as determined by heterospermic A.I. and subsequent paternity testing was not influenced by housing. These results indicate that, in general, housing mature boars in pens enhanced their sex drive and sperm production without affecting semen quality or fertility. However, variations among males in the magnitude of this response were observed so how housing affect sperm production and libido in boars appears to depend on, as of yet, unknown, unique differences among individual males.

Socialization with humans

Research studies conducted over a number of years by Dr. Paul Hemsworth have shown that interactions with humans can limit the productivity and welfare of swine. The critical point of socialization for swine has been shown to occur between 0 and 7 weeks of age (Harayama, 1991). This time frame coincides with the industry's removal of the piglets from the sow at weaning and their movement to the nursery phase of production. Some routine behaviors of people, such as raised voices or impatient gestures, cause young animals to develop fear responses towards humans. These behaviors are a form of stress, which in turn limits growth and reproductive success (Tanida et al., 1995). Several studies have been

conducted to determine the response of piglets to different handlers, as well as their response to adverse handling, in general. These studies revealed that while piglets handled early in life responded better to handling at an older age, they did not discriminate against handlers (Tanida et al., 1995). This suggests that either positive or negative handling early in a pig's life has a lasting effect in terms of how it perceives its interactions with its caretakers in the future. A Human Approach Test (HAT) was the main technique used for determining an animal's fear response to humans in these studies. The HAT was a product of Dr. Hemsworth's studies and it has been used by others to test fear in animals in a number of other studies. In his studies, there was also no difference in response to the adverse handlers or the unfamiliar handler (Hemsworth, 1994). There was, however, a marked difference in response to adverse and positive handlers.

Birth Weight and Litter Size

Wild sows only have an average of five piglets per litter, minimizing runts and allowing the animals a good chance at survival (Morise et al., 2008). Domestic species have evolved and been selected to produce larger litters for production success. Variation in body weight is a common issue in the swine industry and this variability can have significant financial and environmental impact on the producer (Douglas et al., 2013). Adult growth deficiencies can occur due to poor management practices but may also be a direct result of suboptimal birth weight and weaning weight (Stewart and Diekman, 1989).

An increase in litter size has led to higher variation of weight within that litter; birth weights appear to vary more in large litters than in a litter of maybe only six to eight piglets

(Morise et al., 2008). This size difference has been shown to have significant impact on the animal from birth until it is weaned (Douglas et al., 2013); but in some cases can persist until market weight is reached (Morise et al., 2008). An assumption can be made that this is difference before weaning is due to insufficient milk supply from the sow and once the piglet is weaned, it receives the same nutrition as all the others. Large litters will require more nutrients from the sow and some animals are just not able to produce enough milk; if some of the piglets are not fostered and they remain with their mother, they may be at risk for lower growth as adults (Douglas et al., 2013). One study showed that by reducing the number of littermates, the boars were able to grow faster and thus, have increased sperm production as adults (Flowers, 2008). More research needs to be done before this is accepted as fact but it is important to note such details.

A nutrition study conducted by Antipatis and colleagues (2008) showed that limiting the Vitamin A in the diet of the sow during breeding and the first month of pregnancy helped prevent limited fetal growth. In conjunction with the idea of changing the sow's diet to positively affect birth weight, Mateo and colleagues (2007) performed a study where they added L-arginine supplements to the diet of the sow. Arginine prevents fetal growth restriction and allows the fetus to grow to its optimal size. By adding L-arginine, the producers were able to have larger birth weights and eventually larger piglets at weaning.

Parity of the sow has also been shown to affect piglet birth weight and litter size. A gilt will usually produce less live offspring and thus, her piglets may be smaller at birth (Stewart and Diekman, 1989). Low birth weight piglets, studied by F.R. Almeida and colleagues (2013) were shown to have a decreased testis to weight ratio, as well as lower

testicular development and less Sertoli cells at eight days of age. Low birth weight piglets were also studied at eight months of age and did not show these same differences. The only difference was in the number of spermatids. Low birth weight boars had less spermatids in their semen sample than did normal or high birth weight boars of the same age.

A common practice in the swine industry is to foster piglets on or off, depending on the original size of the litter produced by the sow; interesting results have been shown from this practice. Piglets fostered onto a sow had an initial drop in body weight and gained less overall than piglets with their natural mother until the weaning age of 21 days (Stewart and Diekman, 1989). Differences in overall market weight between small and large birth weight pigs persisted, but piglets in smaller nursing litters (whether with their original mother or not) reached market weight five days sooner than those in large nursing litters (Stewart and Diekman, 1989). This is important to note because further studies could be conducted to see if this will impact the swine industry.

Summary

Sperm production in boars is not dependent on any one factor. Temperature, humidity, nutrition, housing, and human interactions all play key roles in affecting sperm production in swine. . On any given individual farm, the majority of these are not directly under the control of the employees that work with the animals on a daily basis. Housing and environmental parameters are directly related to the physical design of the farm and the ventilation system it has in place. Diet formulations typically are done by nutritionists and not farm employees. In contrast, the manner in which pigs socialize to human interactions is

directly and completely the responsibility of farm employees. Previous work involving socialization with humans displayed some interesting results and needs to be evaluated further. Depending on what is discovered, this research area could positively affect the swine industry especially in the management of boars used for artificial insemination.

If there are correlations between birth weight and adult reproductive performance in boars, then birth weight could conceivably be used as a selection criterion for replacement boars. However, to date, there have not been definitive studies examining whether a boar's birth weight has any predictive value for his subsequent sperm production potential as an adult.

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INTRODUCTION

The swine industry is dependent on the successful breeding of sows. These sows are responsible for producing the piglets that are then grown to market age and sold. The industry requires quality boars to produce viable sperm to breed these sows and thus, produce offspring. Consequently, sperm production in boars has a central role in efficient and profitable swine production.

Sperm production in boars is not dependent on any one factor. Temperature, humidity, nutrition, housing, and human interactions all play key roles in affecting sperm production in swine. On any given individual farm, the majority of these are not directly under the control of the employees that work with the animals on a daily basis. Housing and environmental parameters are directly related to the physical design of the farm and the ventilation system it has in place. Diet formulations typically are done by nutritionists and not farm employees. In contrast, the manner in which the pigs socialize to human interactions is directly and completely the responsibility of farm employees.

In contrast, research has shown that interactions with humans can limit the productivity and welfare of swine. Negative interactions cause pigs to fear humans and fear of humans can adversely physiological mechanisms associated with reproductive events (Hemsworth, 2003). This is particularly relevant for A.I. boas. They have close interactions with humans on a regular basis during their collection periods. It is reasonable to assume that they must be comfortable around humans, in general, and the people that collect them. Otherwise, the quantity and quality of their semen may be compromised.

Variation in body weight is a common issue in the swine industry and this variability can have significant financial and environmental impact on the producer (Douglas et al., 2013). Adult growth deficiencies may also be a direct result of suboptimal birth weight (Stewart and Diekman, 1989). Low birth weight pigs may never catch up to their peers. Since a significant portion of the mitotic activity of Sertoli cells occurs prior to birth, it has been suggested that low birth weight boars may have reduced potential for sperm production as adults. At the present time, definitive studies examining this possibility have not been conducted.

The main objective of this study was to examine the effect of human contact and birth weight on adult reproductive performance of boars. Our current understanding of how each of these might affect sperm production is that positive social interactions between humans and boars should have a stimulatory effect due to reduced stress whereas low birth weights would be detrimental due to lack of Sertoli cells. Socialization of boars to humans is a technique that can be done on most farms relatively easily so it has potential for improving semen production in all boars. Management has little control over the birth weight of boars within a litter. Nevertheless, if a significant relationship does exist between birth weight and adult reproductive function, then it could be used as an early selection criterion for replacement boars.

MATERIALS AND METHODS

Animals

The study was conducted between December 5, 2012 and December 18, 2013. The study was conducted at the Swine Educational Unit at North Carolina State University located at 3901 Inwood Drive, Raleigh North Carolina. The Swine Educational Unit (SEU) is a 120 sow farrow-to-finish facility with a closed herd. All boars (n=20) were obtained from litters born between Dec. 5 and Dec. 7, 2012. These boars were from litters of Yorkshire x Landrace x Large White sows bred to Hampshire x Duroc x Pietran boars. There were 0 pairs of full siblings and 19 of the 20 boars used were half siblings.

Farrowing Management and Birth Weight Allocations

Sows were placed in farrowing crates approximately 7 days before their due dates. The farrowing barn contained 12 individual, bow-bar farrowing crates and was equipped with a side-wall baffle ventilation system with an evaporative cooling cell. The bow-bar farrowing crates were 1.5 m wide by 2.5 m long. Each crate had an airplane slat flooring pattern with cement slats underneath the sow; TriBar®, an expanded metal, behind the sows; and Tenderfoot®, a plastic coated wire, in the piglet area. Two heat lamps were also placed at varying heights in each crate as additional heat sources for the piglets. While in the farrowing barn, sows were fed a corn and soybean diet ad libitum two times per day that met or exceeded NRC recommendations for protein, energy, vitamins and minerals for lactating sows (NRC, 2008).

All piglets were processed within 48 hours of birth. Processing included ear notching,

iodine injections, tail docking, and castrating for those boars not on this study. To choose which boars would be involved in the study, the animals were weighed on the day they were born, between 12/5/12 and 12/7/12. They were weighed using a plastic tub and scale placed in the aisle way. A total of ten boars from various litters were chosen as low birth weight pigs, having a birth weight of less than two kilograms (average was 1.1 $\pm$ 0.2 kg). Ten boars were chosen from litters to be part of the high birth weight group, having a birth weight of two kilograms or more (average was 2.0 $\pm$ 0.1 kg). The boars were allowed to remain with their mothers and respective littermates until 21 days of age, when they were weighed and moved to the nursery rooms at the SEU.

Nursery Management and Socialization Allocations

The boars were weighed at weaning on 12/27/2012 using the same plastic tub and scale as the first weight collection period at birth. Testicle height and width were also recorded on each boar, using a digital caliper. Nursery rooms were equipped with side-wall baffle ventilation systems and consisted of six pens on either side of a centrally located hallway. Each pen was 1.82 x 1.82 m with 0.91 m of feeder space and 4 nipple waterers, with 5 boars in each pen for the study. All boars were fed a standard 23% protein starter diet consisting of milk by products for 7-10 days. Following this diet, they received a corn and soybean meal based diet in which the protein percentage gradually decreased to 18%. These diets met or exceeded N.R.C. recommendations for growing pigs between 7 and 35 kg (N.R.C., 2005).

Boars were randomly allocated, within two birth weight groups, to either the

socialized treatment or the unsocialized (control) treatment. When the boars reached five weeks old, the contact/socialization portion of the study began on January 11, 2013 when the boars were 36 days old and continued until February 11, 2013 when the boars were 67 days old. The High contact boars were socialized to humans 3 days per week for 1 hour each day according to the following procedures. The socializer stood in the aisle way of the nursery barn for the first 2.5 weeks. After this she entered the pen with the boars for the last 2.5 The response of each boar on each day was recorded based on the following scale.

0- Backs up when approach

1- Does not approach, but does not back up

2- Comes to front of pen

3- Stays near person while hand extended

4- Allows touching

Once each day, the animals in the Low contact (non-socialized group) were observed by the socializer to make sure all animals were healthy and eating. This took less than 2 minutes. No extra contact was made with these boars by the socializer. All boars in the study were cared for daily by farm personnel not involved with the study. This involved filling up the feeders when they were empty and observing the boars for any signs of discomfort. Farm workers spent an average of 7 minutes in each room each day of the study.

Table 1: Mean Socialization Scores for High and Low Birth Weight Boars. Unsocialized treatments were assigned a score of “0”.

High Birth Weight Socialized (n=5)	High Birth Weight Unsocialized (n=5)	Low Birth Weight Socialized (n=5)	Low Birth Weight Unsocialized (n=5)
2	0	3	0

Finishing Management and Hemsworth Testing

The boars were then moved to the finishing barns when they reached 78 days old (11 weeks). They were weighed and testicle width and height were again recorded in centimeters using a cloth measuring tape. The finishing barn was a curtain-sided environmentally controlled building. The floors were completely slatted with a flush, underslat ventilation system. Misters and cooling fans were programmed to activate when ambient temperatures reached 25.5ºC to provide supplemental cooling for the boars. Each group was placed in a pen together; again five boars per pen. The pens in the finishing barn were 1.84 m wide x 2.84 m long. Each pen contained 2 nipple waterers and a two-hole feeder with 0.91 m feeder space. Boars were fed a corn and soybean meal based diet ad libitum formulated to meet the NRC requirements for growing boars (NRC, 2008).

Two boars died in this stage of production, bringing the total number of boars down to 18. Both boars were in the large birth weight group, one from each contact treatment. It is unclear why they died. Both boars were gaining weight and appeared to be healthy. Necropsy results were unremarkable with all internal organs appearing normal.

Once the boars were 81 days old (11 weeks), each one was subjected to the Hemsworth Test on 2/25/13, 4/1/13, and 5/13/13. The test pen was the same size as a normal, a finishing pen, 1.84 x 2.84m. The person conducting the Hemsworth test stood in the middle of the pen within a small 0.5 m x 1.0 m area. This was considered to be the "area of interest". Boars were placed in the pen with the tester and given a 2 minute adjustment period and then the actual test occurred. Every time the boar entered the area of interest, whether any part of his body penetrated its boundaries or he physically stepped inside the area, this was recorded as Time in Area. Every time the boar made contact with the human or the human's clothes/boots, this was recorded as Human Contact (Hemsworth, 1994). Each test lasted ten minutes. A different person (all female) was used for each of the three tests including the socializer. The boars were also weighed in between Hemsworth testing session while in the finishing barns on 3/19/13 and 5/7/13.

Management of Adult Boars, Training, and Weekly Collections

At 168 days of age (24 weeks), all remaining boars were moved to the gestation barn at the SEU. The gestation barn was a curtain-sided building with underslat ventilation. This barn was also equipped with misters and cooling fans programmed to activate when the ambient temperatures reach 25.5ºC providing additional cooling for the boars. Boars were fed 4 kg of a 14% corn and soybean meal diet daily. This diet was formulated to meet their NRC requirements (NRC, 2008). Each boar was housed separately 2.43 x 1.07 m crates. Location of boars within the barn was chosen randomly. Boars were also weighed at this time, 5/23/13.

On 5/28/13, when the boars were 173 days of age, their collection training began. They were considered trained when they had successfully mounted the dummy sow and been collected for three consecutive days. To train the boars, they were placed in a 2.43m x 3.65 m pen with a dummy sow measuring 0.30 m x 1.21m (Minitube of America, Verona, WI). The dummy was adjusted to a height of 0.67 m so that the boars were able to comfortably mount. The dummy sow was strategically located in the pen so that the boars could move freely on either side and behind the dummy, but not in front of it. Boars were only exposed to the trainer during this part of the study.

Weekly collections from which libido, sperm production, and semen quality data were obtained began 6/18/13 when the boars were 194 days (27 weeks) old. Boars were collected once per week for six months (6/18- 12/18/13). Boars within each treatment combination were randomly assigned after the training period to be collected either on Tuesday or Thursday and then were always collected on that day. Only the socializer knew their specific treatment combinations and this information was not revealed to the collection technician during the study. Collections took place between 0600 and 0900 every Tuesday and Thursday. The order in which the boars were collected each day was randomized.

Reaction time, mounting time, collection time, and time of collection were recorded each time a boar was collected. Reaction time was defined as the time interval between when the boar enters the collection pen until he makes contact with the dummy sow. Mounting time was defined as the time interval between when the boar enters the pen until the boar mounts the collection dummy properly and is ready to be collected. The criteria used to determine a proper mount was as follows: his front legs were off the ground and wrapped

around the barrel of the dummy sow;his chest was in contact with the dummy; and he must have mounted from the rear of the dummy. Collection time was the time interval between when the boar achieved an erection and began to ejaculate and when the boar retracted his penis; dismounted; and walked away from the dummy towards the exit from the collection pen. Time of collection was the time that the collection began. Semen was collected with from all boars with a powder free, polyvinyl glove (IMV America, Eden Prairie, MN) using the gloved hand technique (Almond et al., 1998). Semen was collected into a plastic bag (Minitube of America, Verona, WI). This semen collection bag was placed into a plastic thermos pre-warmed to 37ºC. The weight of the thermos and the plastic bag prior to collection and used as a pre-weight for determining semen volume. The top of the thermos was covered with a milk filter (IMV International, Eden Prairie, MN) which was secured in place with a rubber band. After collection, the milk filter and rubber band were removed and the weight of the thermos containing the ejaculate was recorded using a certified, digital scale (Fisher Scientific, St. Louis, MO). It was assumed that 1 mL of semen was equal to a measurement of 1 g. The pre-weight was subtracted from the total weight and this resulted in a semen weight, which was used as an estimate of semen volume (mL). The number of sperm cells per milliliter was measured using a SpermaCue® (Minitube of America, Verona, WI). A digital thermometer (Fisher Scientific, St. Louis, MO) was used to record the temperature of semen immediately after collection.

After the temperature, volume and sperm concentration were recorded collections were placed in a water bath at 37° C until the first 4 samples of the day were obtained. The time interval between the collection of the first and fourth sample was routinely between 1

hour and 1 hour and 10 minutes. At this time, 1 mL of each of the first four collections was placed in a 50mL disposable centrifuge tube (Fisher Scientific, Atlanta, GA) and then extended out with ReproQuest Preserv Xi extender (ReproQuest, Fitchburg, WI) so that the final concentration in the diluted sample was approximately 50 million sperm per mL. The first 4 samples were placed into a thermos for transportation back to the laboratory in Polk Hall at North Carolina State University, which was roughly 7 miles from the SEU. Transport time was approximately ten minutes. Upon arrival to the laboratory, the temperature of the diluted samples was recorded and all samples were placed in a dry air incubator (Ambi-Hi/Lo; Lab Line Instruments; Melrose Park, IL) until laboratory analyses were conducted. This process was repeated for the last 4 ejaculates as well. The average length of time between collection of the first (number 1) and last (number 8) ejaculate was 127 $\pm$ 5.2 minutes. However, every ejaculate was evaluated in the laboratory within 90 minutes of collection.

Weights and testicular measurements were obtained on 8/20/13, 10/22/13, 11/25/13, and 12/20/2013. Testicle measurements were recorded in cm with a cloth measuring tape.

Semen Quality Analyses

Motility and Mobility

Three µl from the extended sample was removed by pipette (Eppendorf 10 µl) using 10µl Fisherbrand Redi-Tips (Fisher Scientific, Atlanta,GA) This sample was loaded into a Leja slide (Minitube of America, Inc., Verona, WI) pre-warmed to 37°C. Fourteen different estimates of sperm motility were obtained using a computer assisted semen analysis system

(SpermVision®; Minitube of America, Verona, WI) connected to a phase contrast microscope (BMX-41, Olympus, Arlington, VA) Five different microscopic fields were chosen randomly and analyzed and then averaged to obtain an overall estimate of each motility variable for that sample. This overall average was based on about 250 sperm cells. The following motility variables were recorded: proportion of sperm cells exhibiting motility (%); proportion of sperm cells exhibiting progressive forward motility (%); curvilinear distance (um); average path distance (um); straight line distance (um); curvilinear velocity (um/s); average path velocity (um/s); straight line distance (um/s); linearity (straight line velocity / curvilinear velocity); straightness (straight line velocity / average path velocity); wobble (average path velocity / curvilinear velocity); amplitude of lateral head displacement (um); lateral frequency beat (Hz); and average change in orientation of head.

Morphology

One mL of extended semen was placed into a 3 mL test tube (12 x 75mm; Port City Diagnostics, Inc., Wilmington, NC) and 100µl of phosphate buffered saline with 10% formalin was added as a fixative. These tubes were sealed with Parafilm M (American National Co., Greenwich, CT) and left at room temperature for at least 24 hours. The sample was then thoroughly mixed and a 10µl sample was placed onto an ethanol cleaned, glass microscope slide (Fisher Scientific, Atlanta, GA). A coverslip (18 x 18mm; Fisher Scientific, Atlanta, GA) was then placed on top of the sample. The slides were allowed to sit at room temperature for about 1 minute to allow the samples to settle under the cover slip.

The slide was then placed onto the stage of a phase contrast microscope (Zeiss,

Berlin, West Germany). The sample was scanned with the 40x objective until spermatozoa were found. Once spermatozoa were in focus, the objective was moved aside and 1 drop of low viscosity immersion oil was placed on the slide. The oil immersion objective (100x) was then used to evaluate the sample. The percentage of normal acrosomes was calculated from a random sample of 100 cells. Acrosome morphology was determined according to the procedures described by Lovercamp et al. (2013).

A second 10 µl sample was taken from each preserved sample. This sample was placed on an ethanol-cleaned, glass microscope slide and covered with a coverslip. The sample was again viewed under the 100x oil immersion objective. The percentage of morphologically normal sperm cells was calculated from a random sample of 100 cells. Each examined sperm cell was classified into one of the following categories according to the procedures reported previously by Lovercamp et al. (2013):

1. Morphologically normal
2. Head abnormality: Abnormal size or shape of the head
3. Tail abnormality: Abnormal coiling or attachment of the tail
4. Translocated tail: The tail coils completely around the head of the sperm resulting in a paper clip appearance
5. Presence of a distal cytoplasmic droplet
6. Presence of a proximal cytoplasmic droplet

Effect of Different Collection Technicians on Ejaculate Characteristics

Because socialization was a major focus of this study, a portion of the weekly collections were devoted to determining whether boars could discriminate between familiar and novel collection technicians. For 21 of the 27 weeks, boars were collected exclusively by one collection technician who was the same individual boar responsible for training the boars. However, during two separate, 3-week periods each boar was collected once by three different individuals: the person that trained for collection and collected them throughout the majority of the study; the person that socialized one-half of the boars to humans when they were in the nursery phase; and a person who was experienced in collecting boars but had no prior exposure to the boars on the study. The first of these collection periods occurred near the beginning of the study when the boars were 230 days of age and the second near the end when boars were 360 days of age. A different individual was used as the novel collection technician during each of these periods. The novel collection technician was a female for the early period and a male for the late period. This resulted in 32 observations for each type of collection technician. All other aspects of the collection and subsequent analyses were identical to those described previously.

Semen Quality Estimates of Extended, Stored Insemination Doses

With A.I., semen is seldom used on the same day that it is collected and extended. In order to determine whether there were any latent effects of birth weight and socialization on sperm characteristics during storage ejaculates from all boars near the beginning (08/20/2013), middle (10/22/2013), and end (12/10/2013) of the study were fully extended to

industry standards, 3 billion total spermatozoa in 60 mL of extender and monitored over a 7-day period. All samples were extended with Preserv Xi (ReproQuest, Fitchburg,WI) which is semen extender with reduced concentrations of glucose. The low glucose semen extender was chosen since it was better suited for detection of subtle differences in motility characteristics compared with semen extenders that contain increased levels of glucose. Immediate after extension a sample of was obtained from each ejaculate and analyzed for motility characteristics as described previously. This served as the day 0 observation. All samples were placed in a semen storage unit (ReproQuest, Fitchburg, WI) at 17°C. On day 3 and day 7 after collection, motility estimates were recorded from each stored sample as described previously.

Statistical Analyses

All dependent variables associated with body weight and testicular measurements beginning when the boars were 9 weeks old; the Hemsworth Test; and collection and semen quality estimates from the weekly collections and were analyzed with analysis variance procedures for repeated measures for mixed models (Proc Mixed) using SAS® (SAS Inc, Cary, N.C.) The statistical model included the main effects of birth weight (High or Low), socialization (Socialized or Unsocialized); age of boars (27 to 54 weeks) and appropriate interactions. The variance/covariance structure for the repeated measures analyses was determined by finding the structure with the best fit statistics. Boar within each unique combination of birth weight and socialization was treated as a random effect. When this independent variable was significant ($p \leq 0.05$), then it was used to as the error term to test

the main effects of birth weight, socialization and their interaction. When it was not significant, it was assumed that these independent variables, even though they were collected from same boars over time, behaved as if they were independent and the overall experimental error was used to test all main effects and their interactions.

Significant interactions ($p \leq 0.05$) were handled in the following manner. For three-way interactions involving age, birth weight and socialization, the main effects of birth weight, socialization and their interaction were determined for each level of age with analysis variance procedures for a factorial arrangement of treatments (Snedecor and Cochran, 1989). For two-way interactions between birth weight and socialization, the effect of socialization within each birth weight group was determined using a one-way analysis of variance (Snedecor and Cochran, 1989). There were no significant 2-way interactions involving boar age ($p \geq 0.22$). When a significant effect of boar age was found, then changes over time were determined using the Student-Newman-Kuels multiple range test (Snedecor and Cochran, 1989).

Body weight and testicular measurements taken at birth and weaning were analyzed with repeated measures procedures using mixed model procedures of SAS® as described previously. The statistical model also was similar to the one described previously with the exception that socialization and its interactions were not included. Socialization did not occur until the boars were 9 weeks of age, so it could not affect birth or weaning weights.

The cumulative percentages of boars successfully trained to collect from a dummy sow were analyzed with analyses of variance procedures for categorical data (Proc Glimix) using SAS® (SAS Inc, Cary, N.C.). The model consisted of birth weight, socialization, day

of training (1 through 14) and appropriate interactions. Interactions and separation of significant main effects were handled statistically as described previously.

The effect of collection technician was analyzed initially as a three by two by two factorial arrangement of treatments that was repeated at two different time points used mixed model procedures for analysis of variance procedures for repeated measures. The main effects in the statistical model included birth weight (High or Low); socialization (Socialized or Unsocialized); collection technician (trainer; socializer; or novel); age (230 days or 360 days) and their interactions. The error terms for boar nested within each unique combination of birth weight, socialization and collection technician were not significant ($p \geq 0.33$) and, thus, the overall experimental error term was used to test all main effects.

Semen quality estimates of semen stored for 7 days were analyzed as a two by two factorial design that was repeated over time (days 0, 3 and 7) at three different ages. The error terms for boar nested within each unique combination of birth weight, socialization and day of storage were not significant ($p \geq 0.26$) and there were no effects of boar age or their interactions ($p \geq 0.18$). As a result, the statistical model was modified to reflect a simple repeated measures design that included birth weight, socialization, day of storage and their interactions and analyzed with mixed model procedures for analysis of variance for repeated measures. These analyses were similar to those described previously except day of storage replaced boar age in the statistical model. Interactions and separation of means when significant main effects were observed also were handled as previously described.

Two boars died during the study. One boar was removed due to testicular atrophy. One boar could not be trained for semen collection and one boar refused to mount and be

collected during the final 3 weeks of the study. Data from all of these boars remained in the statistical analyses until they were removed from the study.

RESULTS

Body Weights and Testicular Growth

In order to estimate testicular growth, length and width measurements of testes were multiplied together to obtain an estimate of testicular area. Testicular area was then divided by the body weight obtained at the same age to obtain testicular area or size per kg of boar weight. Effects of birth weight and age on body weight, testicular size and testicular size relative to body weight for boars from birth to 21 days of age (weaning) are shown in Tables 2, 3 and 4, respectively. Effects of socialization were not estimated since boars had not yet been exposed to socialization treatments during this period. Body weight at birth in the High birth weight boars (2.0 $\pm$ 0.1 kg) was nearly double ($p < 0.0001$) that of the Low birth weight boars (1.1 $\pm$ 0.1) as expected. However, a significant birth weight by age interaction ($p=0.0026$) was present for body weight (Table 2). Body weight increased in both groups of boars during lactation, but the magnitude of this change was greater in the High birth weight group ($p < 0.0001$) compared with their Low birth weight counterparts ($p = 0.0018$) Testicular size (area) was greater ($p < 0.0018$) in High birth weight boars compared with Low birth weight boars and was larger ($P < 0.0001$) at weaning than at birth in all boars (Table 3). In contrast, testicular size relative to body weight was not influenced by birth weight ($p = 0.6590$) but did decrease ($p < 0.0001$) between birth and weaning (Table 4).

After socialization treatments occurred there was a significant interaction ($p < 0.0001$) among birth weight, socialization and age for body weight. At 63 days of age, High birth weight boars were heavier ($p < 0.0001$) than Low birth weight boar and no effect of socialization was present ($p = 0.21$; Table 5). At 91 and 147 days of age, significant

interactions ($p \leq 0.03$) between birth weight and socialization were present (Tables 6 and 7, respectively). At both of these ages, non-socialized boars weighed more ($p \leq 0.01$) than their socialized contemporaries in the High birth weight treatment, whereas there were no differences ($p \geq 0.19$) in body weight in the Low birth weight boars. After 147 days of age, there were no effects of birth weight or socialization ($p > 0.29$; Tables 8, 9 and 10). Testicular growth in adult boars was not influenced by birth weight or socialization ($p \geq 0.15$; Tables 11 through 16), but did increase ($p \leq 0.05$) between 266 and 322 days of age in all boars (Table 17).

Hemsworth Test

The age of the boars when the Hemsworth tests were conducted did affect any of the dependent variables ($p \geq 0.71$) so test results were averaged across age and are presented in Tables 18 through 23. Neither birth weight nor socialization affected Hemsworth test results ($p \geq 0.18$).

Collection Training

Boars were trained for collection from a dummy sow over a 14-day period. Only one low birth weight, unsocialized boar could not be trained. No effect of birth weight or socialization was seen on the overall training success ($p= 0.78$; Table 24). However, there was a day by birth weight by socialization interaction with regards to how quickly boars were trained to collect during the 14-day period ($p=0.05$). Low birth weight, unsocialized boars required 6 additional days, on average, before they successfully mounted the dummy sow

and were collected compared with the other boars in the study ($p<0.05$; Figure 1).

Reaction, Mounting, and Collection Times

There was a three-way interaction among birth weight, socialization and boar age ($p=0.0124$). When boars were 28 (Table 25), 29 (Table 26) and 50 (Table 27) weeks old, socialization decreased ($p\leq0.03$) reaction times in low birth weight boars, while it had no effect ($p\geq0.11$) on high birth weight boars. At all other ages, no significant effects were observed ($p\geq0.27$; Table 28; Figure 2). Mounting time was not affected by age of the boar, socialization, or birth weight ($p\geq0.11$; Table 29; Figure 3). The birth weight by socialization was significant ($p=0.02$) for collection time (Table 30). Socialization decreased collection time in High birth weight boars ($p=0.01$), but had no effect on their Low birth weight counterparts ($p=0.30$). In general the length of collection decreased with age for all boars ($p<0.0001$; Figure 4).

Semen Characteristics

Semen volume ($p\geq0.65$; Table 31; Figure 5) and concentration of sperm ($p\geq0.24$; Table 32; Figure 6) were not affected by any of the independent variables. In contrast, main effects of birth weight ($P<0.0001$), socialization ($P<0.0001$) and age ($p=0.0004$) were present for total sperm per ejaculate. High birth weight boars averaged 10.4 billion more sperm per ejaculate than low birth weight boars, whereas boars that were socialized produced 10.2 billion additional sperm compared with control boars. These effects were additive so high birth weight boars that were socialized produced over 20 billion more spermatozoa collection

over a 27 week period than their low birth weight, unsocialized contemporaries (Table 33). Total sperm per ejaculate increased ($p \leq 0.05$) from 40.1 billion at 27 weeks of age to70.3 billion at 36 weeks of age and then remained relatively consistent until the collection period stopped when the boars were 54 weeks of age (Figure 7).

Motility and Mobility of Sperm Cells (CASA Analyses)

Birth weight, socialization and boar age interacted to affect the proportion of sperm cells exhibiting any form of motility ($p=0.006$). When boars were 27 weeks old, ejaculates from High birth weight boars had more ($p=0.007$) motile sperm than those from Low birth weight boars (Table 34). During the following week, Low birth weight boars that were socialized had more motile sperm ($p=0.03$) than their unsocialized counterparts, whereas socialization did not influence ($p=0.94$) the proportion of motile spermatozoa for High birth weight boars (birth weight x socialization, $p=0.04$; Table 35). No effects of age ($p=0.24$), birth weight ($p=0.71$) or socialization ($p=0.19$) were present for sperm motility after the boars were 29 weeks old (Figure 8 and Table 36, respectively). In contrast, the proportion of spermatozoa exhibiting progressive forward motility increased as the boars aged ($p<0.0001$; Figure 9), but was not affected by birth weight ($p=0.23$) or socialization ($p=0.85$; Table 37).

Sperm mobility characteristics obtained from CASA analyses can be divided roughly into two categories: those that describe the path and the speed that the average sperm cell takes as it moves through the fluid portion of semen; and those that describe the mechanical action of the sperm cell's tail and head as it travels along this path. Curvilinear distance, path and velocity; straight line distance, path and velocity; straightness; linearity and wobble are

measurements that describe the path and speed of the average sperm cell, while lateral beat frequency, amplitude of lateral head displacement and average change in orientation are used to estimate the mechanics of the head and tail movement. There no effects of socialization ($p>0.15$) or birth weight ($p>0.12$) on any of these mobility parameters (Tables 38 through 49). Each of these sperm motion variables increased as the boars aged ($p<0.0001$) with the exception of straightness, lateral beat frequency and average orientation change. These three variables were affected by boar age ($p<0.0001$), but did not demonstrate any consistent pattern and appeared to randomly fluctuate between high and low levels (Figures 10 through 21).

Morphology of Sperm Cells

No effects of birth weight or socialization were present for the proportion of sperm with normal heads ($p\geq0.39$; Table 50); normal tails ($p>0.21$; Table 51); normal acrosomes ($p\geq0.21$; Table 52) or cytoplasmic droplets ($p\geq0.28$; Table 53). However, all of these morphology variables improved ($p<0.0001$) as the boars aged. The proportion of spermatozoa with normal heads; normal tails; or normal acrosome increased, whereas the proportion of spermatozoa with cytoplasmic droplets decreased (Figures 22 through 25).

Effect of Different Collection Technicians on Collection Success and Ejaculate Characteristics

There were no significant interactions among birth weight, socialization and collection technician ($p\geq0.14$) for all the collection variables with the exception of semen

volume (Table 54) where birth weight did influence how the boars responded to being collected by different individuals. For Low birth weight boars, there was no effect of collection technician ($p=0.59$). In contrast, the individual that trained the boars and the novel technician collected higher volumes ($p \leq 0.05$) than the person that socialized the boars much earlier in the study. For most other ejaculate characteristics, boars seemed to produce higher yields ($p \leq 0.05$) for the trainer and the novel collection technician compared with their socializer (Table 55). It is interesting to note that the trainer was able to successfully collect all the boars during this portion of the study, whereas there were several boars that would not mount the dummy when the novel technician or the person that socialized them attempted the collection.

Semen Quality Estimates of Extended, Stored Insemination Doses

Boar age, birth weight, and socialization did not affect ($p \geq 0.18$) any of the semen quality estimates of spermatozoa extended and stored for 7 days (Tables 56 through 69). However, all measures of semen quality became worse ($p \leq 0.05$) as storage time increased except linearity which remained unchanged (Table 70).

DISCUSSION

The main objective of this study was to determine if birth weight and socialization of boars to humans at a young age had any effect on the reproductive performance of boars used for artificial insemination as adults. The total sperm, concentration of sperm and volume associated with each ejaculate commonly are used to determine if a boar is a successful breeder (Wodsedalek, 1913). This study also evaluated the reaction time, mounting time and collection time of boars for the purpose of evaluating both the competency and libido of the boars (Hemsworth and Tilbrook, 2007). Motility and morphology characteristics of the sperm cells were analyzed in the hope that they would provide estimates of their ability to fertilize ova.

The most significant finding in this study was that birth weight and socialization had an additive effect on total sperm per ejaculate. This resulted in the High birth weight, socialized boars producing, on average, 20 billion more spermatozoa than the Low birth weight, unsocialized boars. Although it is often suggested that the birth weight of boars might be predictive of their sperm production potential as an adult, results from this study are among the first to confirm this speculation objectively. Similarly, socialization of A.I. boars to humans at a young age has not been studied previously, so its positive effect reported in this thesis, also, is a novel observation.

The positive effect of socialization may be related to the boars' familiarity with humans. Since the socialized boars were accustomed to being handled by people at a young age, perhaps, they had reduced fear when being handled during collection and responded by producing more sperm. This perhaps is most evident by the observation that numbers of total

sperm for the low birth weight/socialized boars were similar to those produced by the high birth weight/unsocialized boars which had the lowest production. This shows that there was a direct effect of socialization on low birth weight boars. In essence, by socializing the smaller birth weight boars, it increased their total sperm numbers such that they had similar numbers to high birth weight boars that were not exposed to socialization. Variation in birth weight is a common issue in the swine industry and this variability can have significant financial and performance impacts for the producer (Douglas et al., 2013). Results from this study provide a possible way, through socialization, to remedy the reduced performance of small birth weight boars. There may be benefits to keeping the smaller birth weight boars and by socializing them for a few weeks during their critical period especially if they are unique in their genetic composition.

The advantage of additional weight at birth on total sperm production in this study was of similar magnitude to that of socialization. As a result the combination of high birth weight and socialization produced adult boars that gave the highest amount of total sperm. Previous studies have demonstrated that boars with low birth weights have reduced numbers of Sertoli cells which resulted in fewer spermatids in their testicles when they reached puberty (Almeida et al, 2013). Consequently, it is physiologically reasonable to assume that the same phenomenon occurred in the present study and this resulted in reduced production of sperm in the Low birth weight boars. If this is correct, then a light birth weight could be viewed as affecting sperm production anatomically, while socialization could be viewed as affecting sperm production environmentally through how boars perceive their interaction with humans.

A response to socialization was also seen in reaction and collection times. For reaction time a three way interaction between birth weight, socialization, and time was present. This effect was noticed only in weeks 2, 3 and 23 during the collection weeks of the study. During each of these weeks, there was an effect of socialization on low but not on high birth weight boars. A shorter reaction time indicates a higher libido; the boar noticed the dummy sow quickly and responded in the correct manner. Socialization of the low birth weight boars appeared to shorten reaction time, showing that they responded better to the dummy than their unsocialized counterparts. It is important to note that libido is a hormonal response (Flowers, 2008). However, since this was only observed during 3 of the 27 weeks boars were collected, it appears that improving libido is not a major or consistent effect of socialization.

The only exception to this statement might be in the initial training of A.I. boars. Training success of boars is related to both competency and libido. Twelve of 13 boars that either had high birth weights or were socialized mounted the dummy the first day of training. The only group to not have all boars fully trained by the end of the fourteen day training period was the one with boar with Low birth weights that were not socialized. Moreover, most of the boars in this group did not mount the dummy until at least 6 days after training began. Perhaps, a greater degree of libido is needed for boars to attempt their initial mount. If this is true, then it could explain why a clear effect of socialization was observed during training, but not during routine collections after boars had successfully learned to collect from a dummy sow.

While an overall effect of birth weight, socialization or their interaction was not

important for mounting time, a trend was seen in the Low birth weight boars. The mounting time was slightly increased for those boars that were socialized. While socialization may have helped increase the speed of mounting time for low birth weight boars, the high birth weight boars still had quicker mounting times.

Collection time indicates the amount of time the boar spent on the dummy, ejaculating and being collected. There was an interaction seen between birth weight and socialization on collection time. There was also a random effect of week. Socialization had an impact on the collection time of high birth weight boars; by socializing the high birth weight boars, their collection times actually decreased. This would appear to be an unfavorable response because, in general, a longer collection time means a higher semen volume. Yet, when analyzing semen volume, no effect of birth weight, socialization or their interaction was seen. The effect of socialization on high birth weight boars does not seem to have affected semen volume or even semen concentration so its physiological relevance, at the present time, remains unclear.

While none of the independent variables studied altered semen volume over the entire 27 weeks, there was significant interaction of collector and birth weight during the 6 weeks in which different technicians collected all the boars. High birth weight boars, regardless of socialization status, were affected to a greater degree than their Low weight counterparts by changing collectors. The boars obviously responded differently to each collector and it appeared that they performed the best when collected by the person that they were most familiar with which was the individual that trained them and collected them for the majority of the study. However, it seems that this effect should be not be restricted to just the High

birth weight boars. Moreover, it is surprising that, at least in terms of semen volume, boars produced the lowest amount for the individual that socialized them. However, this observation does support previous work which indicates that pigs do not discriminate between good and bad handling only between positive and negative experiences. It is conceivable that if the boars in the present study had a positive experience during socialization at a young age, then whether they were familiar with the collection technician or not really should not have much effect on their performance.

Nevertheless, once boars decided to mount, reaction, mounting, and collection times did not differ among collectors. It is interesting to speculate that the effect of changing collectors from the boar's perspective may be decided within the first several seconds that the boar enters the collection pen. It is at this point the when the decision is made whether he is comfortable with the collection technician. If he is then he will eventually mount the dummy; allow the technician to collect him; and produce normal ejaculate in terms of sperm quantity and quality. If he is not, then he simply refuses to mount. Clearly, additional studies are needed to fully understand the relationships among birth weight, socialization, and individual collection technicians on production of semen.

A number of motility and morphology parameters of the sperm cells were analyzed in the study. Even though some effects were observed, it is important to recognize that all these estimates were considerably higher than what is typically considered as being excellent in terms of semen quality. For example, motility and morphology estimates from all ejaculates in the study were nearly always greater than 80% and often greater than 90%. Previous research has shown that 60% is the point below which fertility begins to decrease in most

boars for these two parameters (Flowers, 1997). Consequently, ejaculates in the present study were typically 20 to 30% above this level. Therefore, birth weight and socialization do not appear to have major effects on semen quality.

Previous studies have reported that boar with low birth weights have reduced growth potential and remain small, in terms of their body weight, throughout their entire life (Foxcroft et al., 2008). Results from the present study seem to contradict these observations. In general, in the present study, High birth weight boars were heavier than Low birth weight boars until they were approximately 5 months of age after which no differences were observed. What is different about this study is that boar were removed from an ad libitum feeding program and placed on a restricted feeding regimen around 5 months of age. This is a common practice in order to keep boars from getting too big for the size of crates in which they are normally housed. In the studies cited earlier, pigs remained on ad libitum feeding programs. Ad libitum feeding programs are designed to maximize the growth potential since feed is not limited. In contrast, when feed is restricted then ligher animals will experience a slightly faster growth rate than heavier ones because they require nutrients for maintenance and should, in theory, have more available growth. This is most likely what occurred in the present study. High birth weight boars grew at faster rates compared with Low birth weight boars while they were being fed ad libitum. However, once all boars were placed on a restricted feeding regimen, growth rate was slightly higher in the Low compared with the High birth weight boars and remained that way until there was no difference in body weight between the two groups.

What is interesting is that during the portion of the study when boars were fed ad

libitum there were several weigh periods for which there was a socialization by birth weight interaction. In this particular case, Low birth weight boars were not affected by socialization, but it was the unsocialized, High birth weight that had increased weight gains. The nursery phase of production was one of the periods during which this was observed and was also when the boars were socialized via contact with the socializer three times per week. It is possible that while the socialized boars were more interested in the socializer when she was in their nursery room or actually in their nursery pen and were not eating. This potential distraction would not have occurred obviously with the unsocialized boars. Whether this was enough to cause the observed differences in growth, if it did occur at all, is not known and it is puzzling why it also didn't occur for the Low birth weight boars. The physiological explanation for this observation is not clear at the present time.

Testicular growth was estimated by examining changes in the size of testicles referred to as testicular area and testicular area relative to body weight. Testicular area may be indicative of Sertoli cell numbers, as well as fertility of the overall boar (Ford and Wise, 2009; 2011). Neither of these was influenced by socialization in the present study. However, an effect of birth weight was observed for testicular area from birth until the boars were 5 months of age. It appeared increases in testicular area during this time mirrored those observed for body weight. Previous studies have observed a similar relationship between changes in testicular size and body weight (Ford and Wise, 2011). By day 266, testicular area, testicular area per kg of body weight and body weight appeared to have reached a plateau or, at least, entered a significantly reduced growth phase. The increase in total sperm per ejaculate observed in the High birth weight boars adds credence to the idea that changes

in in testicular area were reflective of an increased number of Sertoli cells, albeit not a very precise one.

One of the unique aspects of this study was the development of the scoring system to quantify the degree of socialization in boars. This study used a scale of socialization (0-4) to determine the degree of socialization in the boars at the end of the five week period. Obviously, the unsocialized groups received a score of 0 since they were never tested. The High birth weight boar that were socialized (n=4) had an average score of 2, while their Low birth weight counterparts (n=5) had an average score of 3. According to this scale the Low birth weight boars were slightly more responsive to socialization. It is interesting to note that this was the group that often was responsible for the significant interactions for several of the dependent variables studied later such as reaction time, training success, etc. It would be interesting to determine whether this scoring system could be used to screen boar prospectively for their inclination towards socialization. If this were possible, then this could be used discriminate individuals that could benefit from socialization from those that may not and help producers concentrate any socialization strategies on the boars that would benefit the most from it.

OVERALL CONCLUSIONS

The objective of the study was to determine whether birth weight and socialization affected the reproductive performance of AI boars. Behavior of swine has been studied for years, but the effect of socialization on male reproductive performance had not. It is generally accepted that small birth weight boars will not be as reproductively successful as high birth weight boars. Testicle size is a direct indicator of semen production and usually, as the body weight increases so does the size of the testicles. By introducing socialization to smaller birth weight boars, the study attempted to determine whether birth weight boars could be raised to the same level of productivity as high birth weight boars. The rationale behind this approach is based upon the observations that negative human interaction can cause a boar to be fearful of people and, this, in turn, result in suboptimal reproductive performance.

Socialization appeared to increase total sperm for the low birth weight boars which was expected, but it also had a similar effect on the high birth weight boars well. Socialization either improved or had no effect on several measures of libido and semen quality. Consequently, it appears that it either improves or has not effect on adult reproductive performance of A.I. boars. The fact that it is the act of socialization and not the individual performing the socialization is also important. In the modern swine industry, if socialization strategies are implemented, then it is highly unlikely that the same person socializing future A.I. boars during their nursery phase would be the same individual that would also be collecting them once they entered the boar stud due to biosecurity concerns.

Fortunately, the same individual does not have to be involved with both for a successful outcome.

It is also clear that birth weight can be used as a prospective screening tool for adult reproductive performance of boars. In the present study, the difference in birth weight of the High and Low groups was nearly 100% (2.1 versus 1.1 kg, respectively). What is not known is whether the relationship between these two extremes is linear, quadratic, or resembles some other type of polynomial equation. This information is important if, in fact, it is used an early selection criterion for A.I. boars.

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TABLES

Table 2. Changes in Body Weight in High and Low Birth Weight Boars during Lactation (kg ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Age		
Birth Weight Treatments	Birth	Weaning	Birth Weight means
High	2.1 ± 0.1[a] (5)	8.3 ± 0.3[b] (5)	5.2 ± 0.2 (10)
Low	1.1 ± 0.1[c] (5)	5.6 ± 0.4[d] (5)	3.4 ± 0.3 (10)
Age means	1.6 ± 0.1 (10)	7.0 ± 0.3 (10)	

[a,b] significantly different ($p < 0.0001$)
[c,d] significantly different ($p = 0.0027$)

Table 3. Changes in Testicular Size (area) in High and Low Birth Weight Boars during Lactation ($cm^2 \pm$ s.e). Numbers in parentheses indicate number of observations used to calculate each mean.

	Age		
Birth Weight Treatments	Birth	Weaning	Birth Weight means
High	6.7 ± 0.5 (5)	15.7 ± 0.4 (5)	11.2 ± 1.2[a] (10)
Low	4.0 ± 0.5 (5)	11.5 ± 0.9 (5)	7.8 ± 1.2[b] (10)
Age means	5.4 ± 0.5[c] (10)	13.6 ± 0.8[d] (10)	

[a,b] significantly different ($p = 0.0018$)
[c,d] significantly different ($p < 0.0001$)

Table 4. Changes in Testicular Size relative to Body Weight in High and Low Birth Weight Boars during Lactation (cm^2 / kg $\pm$ s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Age		
Birth Weight Treatments	Birth	Weaning	Birth Weight means
High	3.4 $\pm$ 0.2 (5)	1.9 $\pm$ 0.2 (5)	2.7 $\pm$ 0.1 (10)
Low	3.1 $\pm$ 0.2 (5)	2.0 $\pm$ 0.2 (5)	2.6 $\pm$ 0.1 (10)
Age means	3.3 $\pm$ 0.2[a] (10)	2.0 $\pm$ 0.1[b] (10)	

[a,b] significantly different ($p < 0.0001$)

Table 5. Effect of Birth Weight and Socialization on Body Weight at 63 days of age (kg ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	30.2 ± 1.1 (5)	35.0 ± 1.3 (5)	32.6 ± 1.0[a] (10)
Low	26.4 ± 2.2 (5)	25.9 ± 1.5 (5)	26.2 ± 1.3[b] (10)
Socialization means	28.1 ± 1.4 (10)	31.1 ± 1.9 (10)	

[a,b] significantly different ($p < 0.0001$)

Table 6. Effect of Birth Weight and Socialization on Body Weight at 91 days of age (kg ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	51.3 ± 2.4[a] (5)	60.6 ± 1.1[b] (5)	55.8 ± 2.1 (10)
Low	47.9 ± 3.1[a] (5)	45.6 ± 1.7[a] (5)	47.1 ± 1.9 (10)
Socialization means	49.4 ± 2.0 (10)	54.2 ± 3.1 (10)	

[a,b] means within the same row with different superscripts are different ($p \leq 0.01$)

Table 7. Effect of Birth Weight and Socialization on Body Weight at 147 days of age (kg ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	104.6 ± 3.5[a] (4)	116.7 ± 3.8[b] (4)	110.6 ± 3.3 (8)
Low	100.9 ± 2.9[a] (5)	95.4 ± 1.3[a] (5)	98.9 ± 2.0 (10)
Socialization means	102.5 ± 2.1 (9)	107.6 ± 4.8 (9)	

[a,b] means within the same row with different superscripts are different ($p \leq 0.01$)

Table 8. Effect of Birth Weight and Socialization on Body Weight at 266 days of age (kg ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	138.3 ± 7.1 (4)	154.1 ± 4.5 (4)	146.5 ± 4.8 (8)
Low	148.3 ± 4.0 (5)	149.4 ± 6.4 (3)	148.7 ± 3.2 (8)
Socialization means	144.1 ± 3.9 (9)	152.1 ± 3.6 (7)	

Table 9. Effect of Birth Weight and Socialization on Body Weight at 322 days of age (kg ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	159.0 ± 10.9 (4)	171.1 ± 5.2 (4)	165.0 ± 6.0 (8)
Low	172.4 ± 2.7 (5)	167.4 ± 9.2 (3)	170.5 ± 3.5 (8)
Socialization means	166.4 ± 5.2 (9)	169.5 ± 4.5 (7)	

Table 10. Effect of Birth Weight and Socialization on Body Weight at 378 days of age (kg ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	163.9 ± 16.9 (4)	182.7 ± 9.1 (4)	173.3 ± 9.6 (8)
Low	180.9 ± 3.0 (5)	166.8 ± 8.5 (3)	175.6 ± 4.2 (8)
Socialization means	173.3 ± 7.7 (9)	175.9 ± 6.6 (7)	

Table 11. Effect of Birth Weight and Socialization on Testicular Size (area) at 266 days of age ($cm^2 \pm$ s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	717.0 ± 102.1 (4)	677.6 ± 54.0 (4)	697.3 ± 54.0 (8)
Low	612.3 ± 55.0 (5)	606.3 ± 30.9 (3)	610.0 ± 34.4 (8)
Socialization means	658.8 ± 54.0 (9)	647.1 ± 34.3 (7)	

Table 12. Effect of Birth Weight and Socialization on Testicular Size relative to Body Weight at 266 days of age ($cm^2/kg \pm$ s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	5.2 ± 0.7 (4)	4.5 ± 0.5 (4)	4.8 ± 0.4 (8)
Low	4.1 ± 0.4 (5)	4.1 ± 0.1 (3)	4.1 ± 0.2 (8)
Socialization means	4.6 ± 0.4 (9)	4.3 ± 0.3 (7)	

Table 13. Effect of Birth Weight and Socialization on Testicular Size (area) at 322 days of age (cm^2 ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	971.5 ± 73.4 (4)	862.5 ± 109.4 (4)	917.0 ± 64.0 (8)
Low	877.4 ± 59.9 (5)	756.0 ± 43.3 (3)	831.9 ± 44.5 (8)
Socialization means	919.2 ± 46.6 (9)	816.9 ± 64.4 (7)	

Table 14. Effect of Birth Weight and Socialization on Testicular Size relative to Body Weight at 322 days of age ($cm^2/kg \pm$ s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	6.2 ± 0.5 (4)	5.1 ± 0.4 (4)	5.6 ± 0.5 (8)
Low	5.1 ± 0.4 (5)	4.5 ± 0.1 (3)	4.9 ± 0.3 (8)
Socialization means	5.6 ± 0.3 (9)	4.8 ± 0.4 (7)	

Table 15. Effect of Birth Weight and Socialization on Testicular Size (area) at 378 days of age (cm^2 ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	919.8 ± 76.7 (4)	850.3 ± 132.5 (4)	890.0 ± 66.2 (8)
Low	951.8 ± 50.5 (5)	703.0 ± 66.0 (3)	858.5 ± 58.8 (8)
Socialization means	937.6 ± 41.5 (9)	776.7 ± 74.0 (7)	

Table 16. Effect of Birth Weight and Socialization on Testicular Size relative to Body Weight at 378 days of age ($cm^2/kg \pm$ s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	5.7 ± 0.5 (4)	4.8 ± 1.1 (4)	5.3 ± 0.5 (8)
Low	5.2 ± 0.2 (5)	4.2 ± 0.2 (3)	4.9 ± 0.2 (8)
Socialization means	5.4 ± 0.3 (9)	4.5 ± 0.5 (7)	

Table 17. Age-related Changes (mean $\pm$ s.e.) in Testicular Size and Testicular Size relative to Body Weight in Adult Boars. Numbers in parentheses indicate number of observations used to calculate each mean.

Age (days)	Testicular Size (cm^2)	Testicular Size relative to Body Weight (cm^2/kg)
266	653.7 ± 32.9^{a} (16)	4.5 ± 0.2^{a} (16)
322	874.4 ± 39.3^{b} (16)	5.3 ± 0.3^{b} (16)
378	873.2 ± 42.6^{b} (16)	$5.1 \pm 0.3^{a,b}$ (16)

^{a,b} means with different superscripts in the same column are different ($p \leq 0.05$)

Table 18. Effect of Birth Weight and Socialization on Number of times boar entered the Test area during the Hemsworth Test (mean ± s.e.). The Hemsworth Test was conducted for 10 minutes for each boar. Numbers in parentheses indicate number of observation to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	10.2 ± 2.2 (12)	12.8 ± 2.2 (12)	11.5 ± 0.9 (24)
Low	9.0 ± 1.7 (15)	8.7 ± 1.0 (15)	8.8 ± 0.6 (30)
Socialization means	9.5 ± .8 (27)	10.5 ± 0.7 (27)	

Table 19. Effect of Birth Weight and Socialization on Total time spent in the Test Area during the Hemsworth Test (min ± s.e.). The Hemsworth Test was conducted for 10 minutes for each boar. Numbers in parentheses indicate number of observation to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	2.9 ± 0.9 (12)	3.6 ± 0.4 (12)	3.2 ± 0.3 (24)
Low	3.3 ± 0.9 (15)	3.0 ± 0.7 (15)	3.2 ± 0.3 (30)
Socialization means	3.1 ± 0.3 (27)	3.3 ± 0.2 (27)	

Table 20. Effect of Birth Weight and Socialization on Time of longest single area contact during the Hemsworth Test (min ± s.e.). The Hemsworth Test was conducted for 10 minutes for each boar. Numbers in parentheses indicate number of observation to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	1.0 ± 0.4 (12)	0.8 ± 0.2 (12)	0.9 ± 0.2 (24)
Low	1.0 ± 0.3 (15)	0.9 ± 0.2 (15)	1.0 ± 0.1 (30)
Socialization means	1.0 ± 0.2 (27)	0.9 ± 0.1 (27)	

Table 21. Effect of Birth Weight and Socialization on Number of times boar touches human during the Hemsworth Test (mean ± s.e.). The Hemsworth Test was conducted for 10 minutes for each boar. Numbers in parentheses indicate number of observation to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	4.1 ± 1.2 (12)	5.3 ± 1.2 (12)	4.7 ± 0.5 (24)
Low	5.1 ± 1.6 (15)	4.2 ± 0.9 (15)	4.7 ± 0.5 (30)
Socialization means	4.7 ± 0.6 (27)	4.7 ± 0.4 (27)	

Table 22. Effect of Birth Weight and Socialization on Total time spent touching human during the Hemsworth Test (min ± s.e.). The Hemsworth Test was conducted for 10 minutes for each boar. Numbers in parentheses indicate number of observation to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	0.9 ± 0.5 (12)	2.3 ± 0.4 (12)	1.1 ± 0.2 (24)
Low	1.6 ± 0.8 (15)	1.2 ± 0.4 (15)	1.4 ± 0.2 (30)
Socialization means	1.3 ±0.3 (27)	1.3 ± 0.2 (27)	

Table 23. Effect of Birth Weight and Socialization on Time of longest single human contact during the Hemsworth Test (min ± s.e.). The Hemsworth Test was conducted for 10 minutes for each boar. Numbers in parentheses indicate number of observation to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	0.4 ± 0.2 (12)	0.5 ± 0.2 (12)	0.5 ± 0.1 (24)
Low	0.6 ± 0.3 (15)	0.5 ± 0.2 (15)	0.6 ± 0.1 (30)
Socialization means	0.5 ±0.1 (27)	0.5 ± 0.1 (27)	

Table 24. Effect of Birth Weight and Socialization on Training Success (%) at the End of the Two Week Training Period. Numbers in parentheses indicate proportion of boars that were successfully trained.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	100 (4/4)	100 (4/4)	100 (8/8)
Low	100 (5/5)	75 (3/4)	89 (8/9)
Socialization means	100 (9/9)	88 (7/8)	

Table 25. Effect of Socialization on Reaction Time at Week 1 of Collection. (s ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

Birth Weight Treatments	Socialization Treatments: High	Socialization Treatments: Low	Birth Weight means
High	2.0 ± 0.4[a] (4)	1.3 ± 0.3[a] (4)	1.7 ± 0.3 (8)
Low	1.6 ± 0.4[a] (5)	3.7 ± 0.7[b] (3)	2.4 ± 0.5 (8)
Socialization means	1.8 ±0.4 (9)	2.3 ± 0.4 (7)	

[a,b] means within the same row with different superscripts are different ($p \leq 0.05$)

Table 26. Effect of Socialization on Reaction Time at Week 2 of Collection (s ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	4.0 ± 1.1[a] (4)	1.8 ± 0.5[a] (4)	2.9 ± 0.7 (8)
Low	2.8 ± 0.4[a] (5)	5.3 ± 0.9[b] (3)	3.8 ± 0.6 (8)
Socialization means	3.3 ±0.5 (9)	3.3 ± 0.8 (7)	

[a,b] means within the same row with different superscripts are different ($p \leq 0.05$)

Table 27. Effect of Socialization on Reaction Time at Week 23 of Collection. (s ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

Birth Weight Treatments	Socialization Treatments: High	Socialization Treatments: Low	Birth Weight means
High	2.3 ± 0.5[a] (4)	1.8 ± 0.5[a] (4)	2.0 ± 0.4 (8)
Low	1.4 ± 0.3[a] (5)	3.6 ± 0.3[b] (3)	2.3 ± 0.5 (8)
Socialization means	1.7 ±0.3 (9)	2.6 ± 0.5 (7)	

[a,b] means within the same row with different superscripts are different ($p \leq 0.05$)

Table 28. Effect of Birth Weight and Socialization on Reaction Time (s ± s.e.) during Weeks 1, 4 through 22, and 24 through 27 of the study. Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	3.3± 0.4 (96)	2.3 ± 0.2 (92)	2.8 ± 0.2 (188)
Low	2.2 ± 0.2 (119)	5.6 ± 1.7 (72)	3.5 ± 0.7 (191)
Socialization Means	2.7 ± 0.2 (215)	3.8 ± 0.8 (163)	

Table 29. Effect of Birth Weight and Socialization on Mounting Time (s ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight Means
High	54.6 ± 5.0 (108)	65.3 ± 6.7 (104)	59.9 ± 4.2 (212)
Low	100.4 ± 9.4 (134)	61.3 ± 10.2 (80)	85.8 ± 7.1 (214)
Socialization Means	80.0 ± 5.8 (242)	63.5 ± 5.9 (184)	

Table 30. Effect of Birth Weight and Socialization on Collection Time (s ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	259.6 ± 6.0[a] (108)	281.5 ± 6.1[b] (104)	270.3 ± 4.3 (212)
Low	252.4 ± 6.4[a] (134)	241.7 ± 8.2[a] (80)	248.4 ± 5.1 (214)
Socialization means	255.6 ± 4.5 (242)	264.2 ± 5.2 (184)	

[a,b] means with different superscripts in the same row are different ($p \leq 0.05$)

Table 31. Effect of Birth Weight and Socialization on Semen Volume (mL ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	155.6 ± 4.1 (108)	170.0 ± 4.6 (104)	162.7 ± 3.1 (212)
Low	162.8 ± 4.2 (134)	128.2 ± 2.8 (80)	149.8 ± 3.1 (214)
Socialization means	159.6 ± 3.0 (242)	151.8 ± 3.3 (184)	

Table 32. Effect of Birth Weight and Socialization on Sperm Concentration (million/mL ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	512.9 ± 18.1 (108)	403.6 ± 14.3 (104)	459.3 ± 12.1 (212)
Low	441.8 ± 17.8 (134)	430.9 ± 16.0 (80)	437.7 ± 12.6 (214)
Socialization means	473.5 ± 12.9 (242)	415.5 ± 10.6 (184)	

Table 33. Effect of Birth Weight and Socialization on Total Sperm (billion ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	77.0 ± 2.8 (108)	64.4 ± 1.8 (104)	70.8 ± 1.7[a] (212)
Low	65.8 ± 2.0 (134)	54.1 ± 1.9 (80)	61.4 ± 1.5[b] (214)
Socialization means	70.7 ± 1.7[c] (242)	59.5 ± 1.4[d] (184)	

[a,b] means with different superscripts are different ($p < 0.0001$)
[c,d] means with different superscripts are different ($p < 0.0001$)

Table 34. Effect of Birth Weight, Socialization, and Age on Motility for Week 1 of Collection. (% ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	93.8 ± 0.4 (4)	91.6 ± 1.9 (4)	92.7 ± 1.0[a] (8)
Low	84.6 ± 3.6 (5)	80.8 ± 4.7 (3)	83.2 ± 2.8[b] (8)
Socialization means	88.7 ± 2.5 (9)	86.9 ± 3.0 (7)	

[a,b] means with different superscript are different (p=0.0073)

Table 35. Effect of Birth Weight and Age on Motility for Week 2 of Collection. (% ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	92.1 ± 1.8[a] (4)	92.0 ± 2.1[a] (4)	92.5 ± 1.3 (8)
Low	91.8 ± 1.7[a] (5)	82.9 ± 3.3[b] (3)	88.5 ± 2.2 (8)
Socialization means	92.0 ± 1.2 (9)	88.1 ± 2.5 (7)	

[a,b] means within the same row with different superscripts are different ($p \leq 0.05$)

Table 36. Effect of Birth Weight and Socialization on Motility for Weeks 3-27 of Collection. (% ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	90.1 ± 1.0 (100)	90.0 ± 0.9 (96)	90.5 ± 0.7 (196)
Low	87.8 ± 1.2 (124)	96.5 ± 6.3 (74)	91.1 ± 1.1 (198)
Socialization means	88.8 ± 1.8 (224)	92.8 ± 3.4 (170)	

Table 37. Effect of Birth Weight and Socialization on Progressive Motility. (% ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	77.4 ± 1.5 (108)	75.2 ± 1.4 (104)	77.0 ± 1.0 (212)
Low	73.4 ± 1.7 (134)	69.3 ± 2.0 (80)	71.9 ± 1.3 (214)
Socialization means	75.2 ± 1.2 (242)	73.4 ± 1.2 (184)	

Table 38. Effect of Birth Weight and Socialization on Curvilinear Distance.(um ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	63.9 ± 1.9 (108)	60.8 ± 1.7 (104)	62.5 ± 1.3 (212)
Low	61.3 ± 1.8 (134)	57.7 ± 2.0 (80)	59.6 ± 1.3 (214)
Socialization means	62.3 ± 1.3 (242)	59.7 ± 1.3 (184)	

Table 39. Effect of Birth Weight and Socialization on Average Path Distance.(um ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	34.6 ± 1.0 (108)	32.5 ± 1.8 (104)	33.6 ± 0.7 (212)
Low	33.4 ± 1.0 (134)	30.8 ± 1.2 (80)	32.4 ± 0.8 (214)
Socialization means	33.9 ± 0.7 (242)	31.8 ± 0.8 (184)	

Table 40. Effect of Birth Weight and Socialization on Straight Line Distance.(um ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	25.0 ± 0.8 (108)	24.1 ± 0.9 (104)	24.5 ± 0.6 (212)
Low	24.8 ± 0.8 (134)	22.7 ± 1.0 (80)	24.0 ± 0.6 (214)
Socialization means	24.5 ± 0.5 (242)	23.5 ± 0.6 (184)	

Table 41. Effect of Birth Weight and Socialization on Curvilinear Velocity.(um/s ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	143.5 ± 4.3 (108)	136.7 ± 4.2 (104)	140.1 ± 3.0 (212)
Low	136.2 ± 4.0 (134)	128.8 ± 4.5 (80)	133.5 ± 3.0 (214)
Socialization means	139.5 ± 2.9 (242)	133.2 ± 0.6 (184)	

Table 42. Effect of Birth Weight and Socialization on Average Path Velocity (um/s ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	77.7 ± 2.6 (108)	77.7 ± 2.4 (104)	75.4 ± 1.8 (212)
Low	74.8 ± 2.2 (134)	69.1 ± 2.7 (80)	72.7 ± 1.7 (214)
Socialization means	76.1 ± 1.7 (242)	71.3 ± 1.8 (184)	

Table 43. Effect of Birth Weight and Socialization on Straight Line Velocity (um/s ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	56.4 ± 1.8 (108)	54.1 ± 1.9 (104)	55.3 ± 1.3 (212)
Low	55.8 ± 1.7 (134)	50.9 ± 2.3 (80)	54.0 ± 1.4 (214)
Socialization means	56.1 ± 1.3 (242)	52.7 ± 1.5 (184)	

Table 44. Effect of Birth Weight and Socialization on Linearity (mean ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	0.39 ± 0.01 (108)	0.39 ± 0.01 (104)	0.39 ± 0.01 (212)
Low	0.41 ± 0.01 (134)	0.39 ± 0.01 (80)	0.40 ± 0.01 (214)
Socialization means	0.40 ± 0.01 (242)	0.39 ± 0.01 (184)	

Table 45. Effect of Birth Weight and Socialization on Amplitude of Head Displacement (um ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	4.28 ± 0.10 (108)	3.94 ± 0.10 (104)	4.11 ± 0.07 (212)
Low	3.90 ± 0.09 (134)	3.76 ± 0.10 (80)	3.85 ± 0.07 (214)
Socialization means	4.07 ± 0.07 (242)	3.86 ± 0.07 (184)	

Table 46. Effect of Birth Weight and Socialization on Straightness (mean ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	0.72 ± 0.01 (108)	0.74 ± 0.01 (104)	0.73 ± 0.01 (212)
Low	0.74 ± 0.01 (134)	0.73 ± 0.01 (80)	0.74 ± 0.01 (214)
Socialization means	0.73 ± 0.01 (242)	0.73 ± 0.01 (184)	

Table 47. Effect of Birth Weight and Socialization on Wobble (mean ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	0.54 ± 0.01 (108)	0.53 ± 0.01 (104)	0.54 ± 0.01 (212)
Low	0.55 ± 0.01 (134)	0.53 ± 0.01 (80)	0.54 ± 0.01 (214)
Socialization means	0.55 ± 0.01 (242)	0.53 ± 0.01 (184)	

Table 48. Effect of Birth Weight and Socialization on Beat, Lateral Frequency (Hz ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	35.1 ± 0.4 (108)	35.6 ± 0.4 (104)	35.4 ± 0.3 (212)
Low	35.5 ± 0.5 (134)	34.6 ± 0.8 (80)	35.2 ± 0.4 (214)
Socialization means	35.3 ± 0.3 (242)	35.2 ± 0.4 (184)	

Table 49. Effect of Birth Weight and Socialization on Average Orientation Change (mean ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	16.9 ± 0.4 (108)	16.6 ± 0.4 (104)	16.8 ± 0.3 (212)
Low	17.4 ± 0.4 (134)	15.8 ± 0.5 (80)	16.8 ± 0.3 (214)
Socialization means	17.2 ± 0.3 (242)	16.3 ± 0.3 (184)	

Table 50. Effect of Birth Weight and Socialization on Normal Heads (% ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	93.4 ± 0.2 (108)	93.3 ± 0.3 (104)	93.2 ± 0.2 (212)
Low	93.1 ± 0.3 (134)	93.0 ± 0.3 (80)	93.2 ± 0.2 (214)
Socialization means	93.2 ± 0.2 (242)	93.1 ± 0.2 (184)	

Table 51. Effect of Birth Weight and Socialization on Normal Tails (% ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	94.0 ± 0.3 (108)	93.5 ± 0.4 (104)	93.4 ± 0.2 (212)
Low	94.0 ± 0.3 (134)	94.1 ± 0.3 (80)	94.0 ± 0.2 (214)
Socialization means	94.0 ± 0.2 (242)	93.8 ± 0.3 (184)	

Table 52. Effect of Birth Weight and Socialization on Normal Acrosome (% ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	92.1 ± 0.3 (108)	90.4 ± 0.7 (104)	91.3 ± 0.4 (212)
Low	91.1 ± 0.4 (134)	90.7 ± 0.4 (80)	91.0 ± 0.3 (214)
Socialization means	91.5 ± 0.3 (242)	90.5 ± 0.4 (184)	

Table 53. Effect of Birth Weight and Socialization on Sperm with cytoplasmic droplets (% ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	4.8 ± 0.3 (108)	5.8 ± 0.4 (104)	5.3 ± 0.2 (212)
Low	5.3 ± 0.3 (134)	6.4 ± 0.3 (80)	5.7 ± 0.2 (214)
Socialization means	5.1 ± 0.2 (242)	6.0 ± 0.2 (184)	

Table 54. Interaction between Collection Technician and Birth Weight for Semen Volume (mL ± s.e.) during the 6 weeks of the Study when all Boars were collected by their Trainer, Socializer, and a Novel person. Numbers in parentheses indicate number of observations used to calculate each mean.

	Birth Weight Treatments		
Collection Technician	High	Low	Technician means
Trainer	177.0 ± 10.4[a] (15)	162.9 ± 15.4[a] (16)	169.7 ± 9.3 (31)
Socializer	119.4± 10.8[b] (13)	142.0 ± 14.4[a] (12)	131.1 ± 9.1 (25)
Novel Person	187.0 ± 15.8[a] (12)	137.9 ± 11.5[a] (12)	161.9 ± 10.5 (24)
Birth Weight means	161.3 ± 8.4 (40)	147.6 ± 8.0 (40)	

[a,b] means within the same column with different superscripts are different ($p \leq 0.05$)

Table 55. Effect of Collection Technician (mean ± s.e.) on Collection Parameters. The Trainer successfully collected all boars, whereas the Socializer and the Novel person did not (Successful Collections). Numbers of observations for other collection parameters are based on the number of successful collections for each collector.

	Collection Technician		
Collection Variable	Trainer	Socializer	Novel
Successful Collections (%)	100.0[a] (31/31)	80.6 ± 7.2[b] (25/31)	77.4 ± 7.6[b] (24/31)
Reaction Time (s)	3.5 ± 0.7	2.8 ± 0.7	2.5 ± 0.4
Mounting Time (s)	96.2 ± 24.5	58.4 ± 10.5	88.8 ± 17.5
Total Sperm (x 10^9)	72.6 ± 4.0	61.7 ± 3.4	71.2 ± 4.5

[a,b] means within the same row with different superscripts are different ($p \leq 0.05$)

Table 56. Effect of Birth Weight and Socialization on Motility of Extended, Stored Insemination Doses (% ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	61.7 ± 4.4 (36)	56.9 ± 5.0 (33)	59.4 ± 3.3 (69)
Low	65.2 ± 3.8 (45)	48.0 ± 5.9 (27)	58.8 ± 3.4 (72)
Socialization means	63.7 ± 2.9 (81)	52.9 ± 3.8 (60)	

Table 57. Effect of Birth Weight and Socialization on Progressive Motility of Extended, Stored Insemination Doses (% ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	48.7 ± 4.7 (36)	44.9 ± 5.2 (33)	46.9 ± 3.5 (69)
Low	50.1 ± 4.0 (45)	33.9 ± 5.9 (27)	44.0 ± 3.4 (72)
Socialization means	49.5 ± 3.0 (81)	39.9 ± 3.9 (60)	

Table 58. Effect of Birth Weight and Socialization on Curvilinear Distance of Extended, Stored Insemination Doses (um ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	54.8 ± 3.8 (36)	50.5 ± 3.1 (33)	52.7 ± 2.5 (69)
Low	53.1 ± 2.7 (45)	46.1 ± 3.7 (27)	50.5 ± 2.2 (72)
Socialization means	53.8 ± 2.3 (81)	48.5 ± 2.4 (60)	

Table 59. Effect of Birth Weight and Socialization on Average Path Distance of Extended, Stored Insemination Doses (um ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	31.0 ± 1.8 (36)	27.8 ± 1.4 (33)	29.5 ± 1.2 (69)
Low	29.2 ± 1.3 (45)	26.0 ± 1.8 (27)	28.0 ± 1.1 (72)
Socialization means	30.0 ± 1.1 (81)	27.0 ± 1.1 (60)	

Table 60. Effect of Birth Weight and Socialization on Straight Line Distance of Extended, Stored Insemination Doses (um ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	19.2 ± 1.2 (36)	17.6 ± 1.1 (33)	18.4 ± 0.8 (69)
Low	18.5 ± 1.0 (45)	17.6 ± 1.4 (27)	18.2 ± 0.8 (72)
Socialization means	18.8 ± 0.7 (81)	17.6 ± 0.9 (60)	

Table 61. Effect of Birth Weight and Socialization on Curvilinear Velocity of Extended, Stored Insemination Doses (um/s ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	123.7 ± 8.8 (36)	112.4 ± 7.1 (33)	118.3 ± 5.7 (69)
Low	118.9 ± 6.2 (45)	104.2 ± 8.2 (27)	113.4 ± 5.0 (72)
Socialization means	121.0 ± 5.2 (81)	108.7 ± 5.3 (60)	

Table 62. Effect of Birth Weight and Socialization on Average Path Velocity of Extended, Stored Insemination Doses (um/s ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	70.0 ± 4.0 (36)	62.0 ± 3.3 (33)	66.2 ± 2.7 (69)
Low	65.4 ± 3.1 (45)	59.4 ± 4.0 (27)	63.2 ± 2.4 (72)
Socialization means	67.4 ± 2.5 (81)	60.8 ± 2.5 (60)	

Table 63. Effect of Birth Weight and Socialization on Straight Line Velocity of Extended, Stored Insemination Doses (um/s ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	43.6 ± 2.7 (36)	37.8 ± 2.5 (33)	41.7 ± 1.9 (69)
Low	41.8 ± 2.2 (45)	40.4 ± 3.1 (27)	41.3 ± 1.8 (72)
Socialization means	42.6 ± 1.7 (81)	40.1 ± 1.9 (60)	

Table 64. Effect of Birth Weight and Socialization on Linearity of Extended, Stored Insemination Doses (mean ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	0.38 ± 0.02 (36)	0.36 ± 0.01 (33)	0.37 ± 0.01 (69)
Low	0.36 ± 0.01 (45)	0.42 ± 0.01 (27)	0.38 ± 0.01 (72)
Socialization means	0.37 ± 0.01 (81)	0.38 ± 0.01 (60)	

Table 65. Effect of Birth Weight and Socialization on Straightness of Extended, Stored Insemination Doses (mean ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	0.63 ± 0.02 (36)	0.63 ± 0.01 (33)	0.63 ± 0.01 (69)
Low	0.64 ± 0.01 (45)	0.69 ± 0.02 (27)	0.66 ± 0.01 (72)
Socialization means	0.63 ± 0.01 (81)	0.66 ± 0.01 (60)	

Table 66. Effect of Birth Weight and Socialization on Wobble of Extended, Stored Insemination Doses (mean ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	0.59 ± 0.01 (36)	0.57 ± 0.01 (33)	0.58 ± 0.01 (69)
Low	0.57 ± 0.01 (45)	0.60 ± 0.01 (27)	0.58 ± 0.01 (72)
Socialization means	0.58 ± 0.01 (81)	0.58 ± 0.01 (60)	

Table 67. Effect of Birth Weight and Socialization on Beat, Lateral Frequency of Extended, Stored Insemination Doses (Hz ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	28.5 ± 1.3 (36)	27.6 ± 1.2 (33)	28.1 ± 0.9 (69)
Low	28.2 ± 1.2 (45)	25.6 ± 1.7 (27)	27.3 ± 1.0 (72)
Socialization means	28.4 ± 0.9 (81)	26.7 ± 1.0 (60)	

Table 68. Effect of Birth Weight and Socialization on Amplitude Head Displacement of Extended, Stored Insemination Doses (um ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	4.2 ± 0.2 (36)	3.6 ± 0.2 (33)	3.8 ± 0.1 (69)
Low	3.7 ± 0.2 (45)	3.4 ± 0.2 (27)	3.6 ± 0.1 (72)
Socialization means	3.9 ± 0.1 (81)	3.5 ± 0.1 (60)	

Table 69. Effect of Birth Weight and Socialization on Average Orientation Change of Extended, Stored Insemination Doses (mean ± s.e.). Numbers in parentheses indicate number of observations used to calculate each mean.

	Socialization Treatments		
Birth Weight Treatments	High	Low	Birth Weight means
High	15.5 ± 0.8 (36)	15.0 ± 0.8 (33)	15.2 ± 0.6 (69)
Low	15.7 ± 0.6 (45)	14.0 ± 0.9 (27)	15.1 ± 0.5 (72)
Socialization means	15.6 ± 0.5 (81)	15.3 ± 0.6 (60)	

Table 70. Effect of Storage of Extended Semen for 7 days on Sperm Quality Estimates (mean ± s.e.; n = 47 per day).

	Day		
Sperm Quality Estimates	0	3	7
Motility (%)	89.5 ± 1.7[a]	46.9 ± 2.9[b]	40.8 ± 3.0[b]
Progressive Motility (%)	76.9 ± 2.4[a]	30.2 ± 2.7[b]	29.2 ± 2.9[b]
Curvilinear Distance (um)	64.6 ± 2.3[a]	45.3 ± 2.3[b]	44.8 ± 3.0[b]
Average Path Distance (um)	34.8 ± 1.3[a]	25.6 ± 1.0[b]	25.7 ± 1.3[b]
Straight Line Distance (um)	24.4 ± 0.9[a]	15.0 ± 0.6[b]	15.6 ± 0.7[b]
Curvilinear Velocity (um/s)	146.2 ± 4.6[a]	100.9 ± 5.1[b]	100.2 ± 6.2[b]
Average Path Velocity (um/s)	79.0 ± 3.2[a]	57.2 ± 2.3[b]	57.8 ± 2.8[b]
Straight Line Velocity (um/s)	55.4 ± 2.2[a]	33.7 ± 1.3[b]	35.5 ± 1.5[b]
Straightness	0.70 ± 0.01[a]	0.60 ± 0.01[b]	0.63 ± 0.01[b]
Linearity	0.38 ± 0.01	0.36 ± 0.01	0.39 ± 0.02
Wobble	0.54 ± 0.01[a]	0.59 ± 0.01[b]	0.61 ± 0.02[b]
Lateral Beat Frequency (Hz)	35.0 ± 0.6[a]	25.3 ± 1.0[b]	22.7 ± 0.9[c]
Average Orientation Change	17.6 ± 0.6[a]	14.4 ± 0.6[b]	13.4 ± 0.7[b]
Amplitude of Lateral Head Displacement (um)	4.4 ± 0.2[a]	3.5 ± 0.1[b]	3.3 ± 0.2[b]

[a,b,c] means within the same row with different superscripts are different ($p \leq 0.05$)

FIGURES

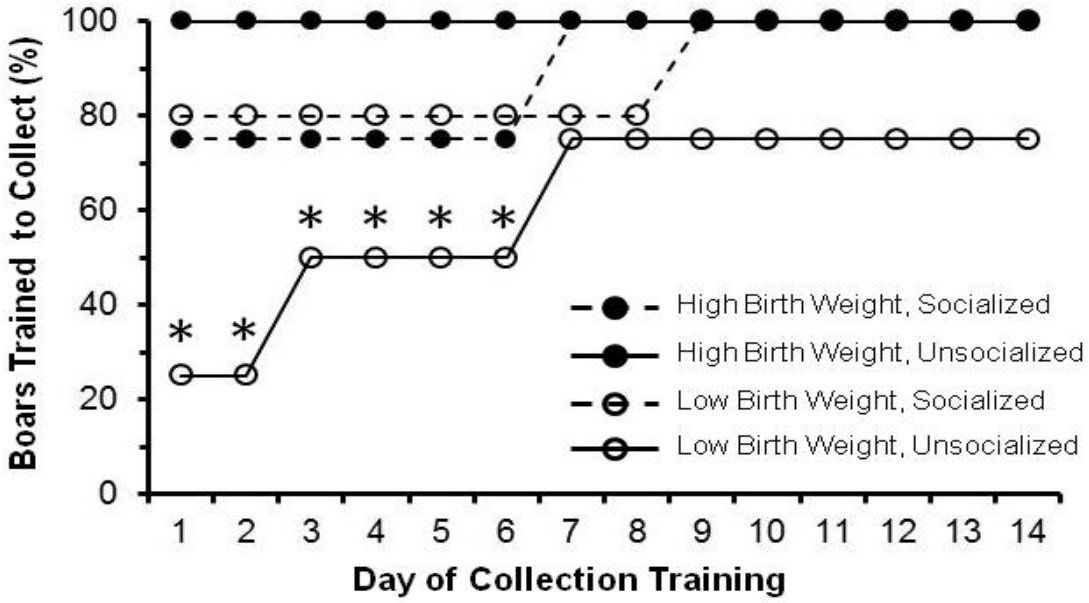

Figure 1. Effect of Birth Weight and Socialization on the Cumulative Success Rate of Training Boars to Collect from a Dummy Sow. Means with an * are significantly different from other means.

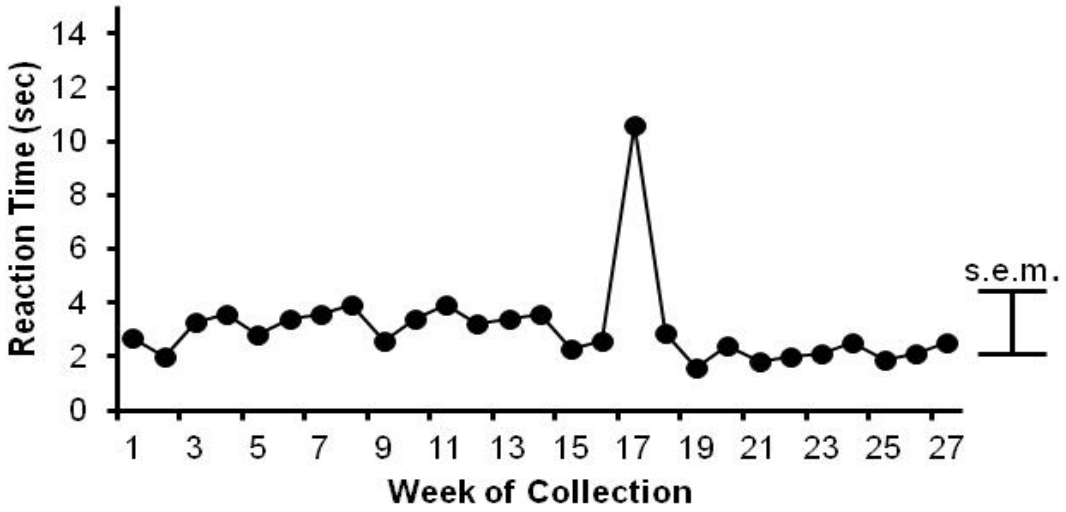

Figure 2. Effect of Week of Collection on Reaction Time. Boars were 27 and 54 weeks of age when the collections began and ended, respectively. Standard error of the mean = 0.9 seconds.

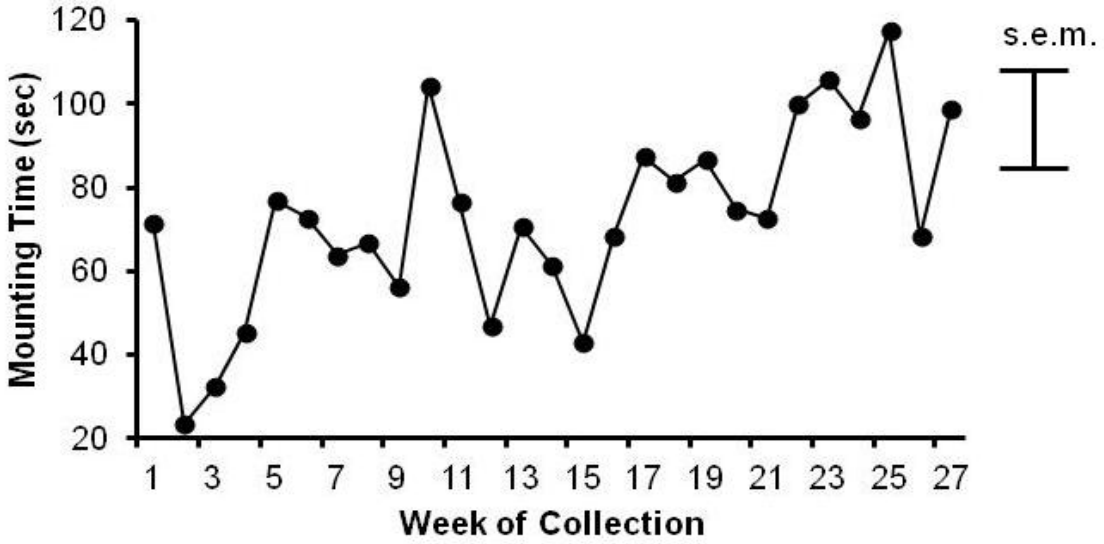

Figure 3. Effect of Week of Collection on Mounting Time. Boars were 27 and 54 weeks of age when the collections began and ended, respectively. Standard error of the mean = 20.2 seconds.

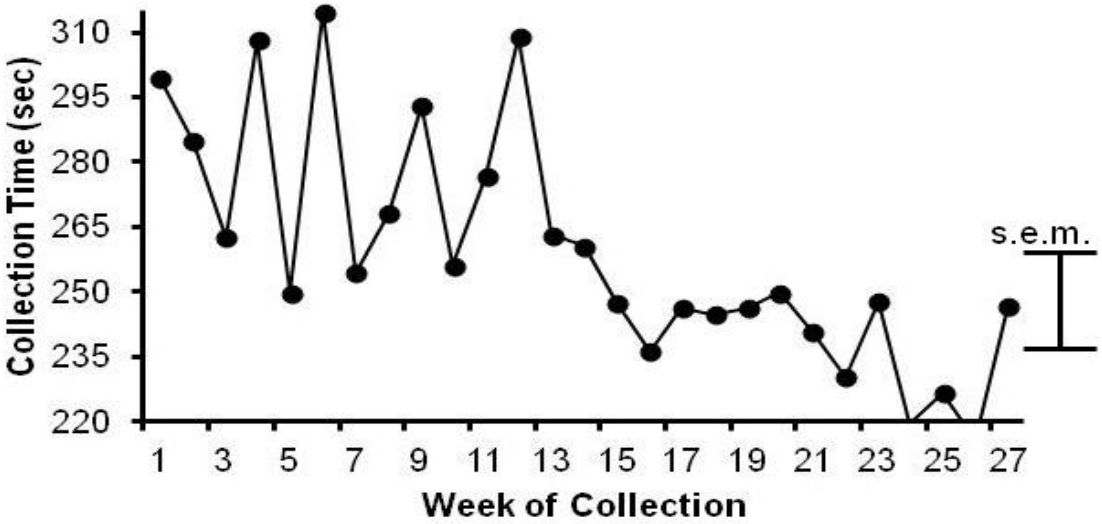

Figure 4. Effect of Week of Collection on Collection Time. Boars were 27 and 54 weeks of age when the collections began and ended, respectively. Standard error of the mean = 16.4 seconds.

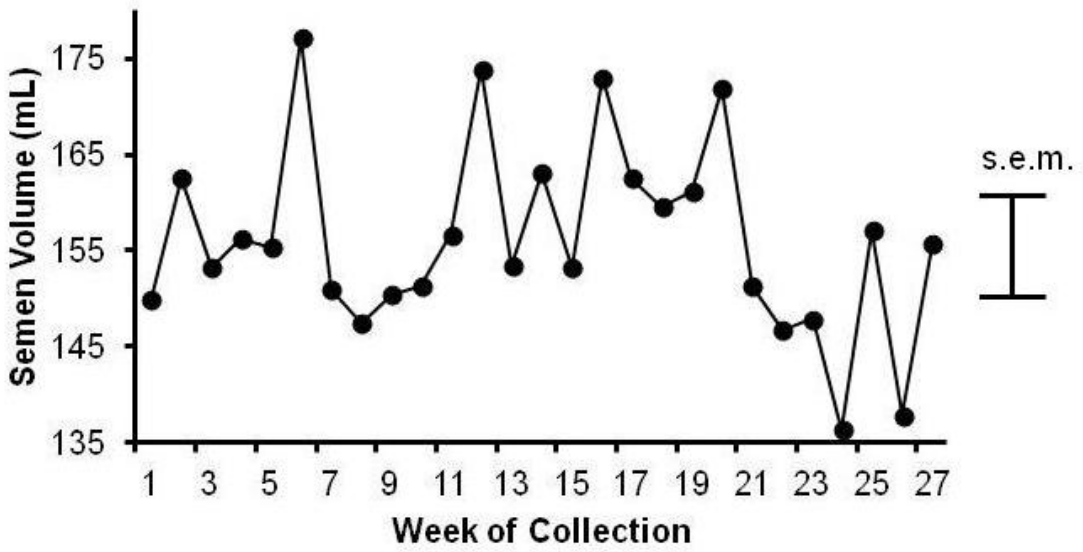

Figure 5. Effect of Week of Collection on Semen Volume. Boars were 27 and 54 weeks of age when the collections began and ended, respectively. Standard error of the mean = 11.4 mL.

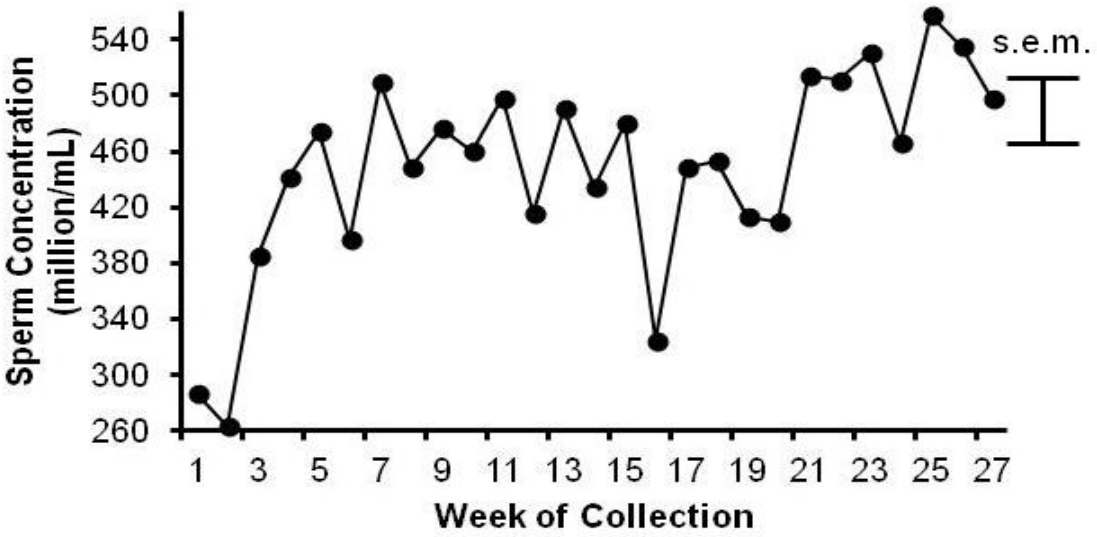

Figure 6. Effect of Week of Collection on Sperm Concentration. Boars were 27 and 54 weeks of age when the collections began and ended, respectively. Standard error of the mean = 42.4 million/mL.

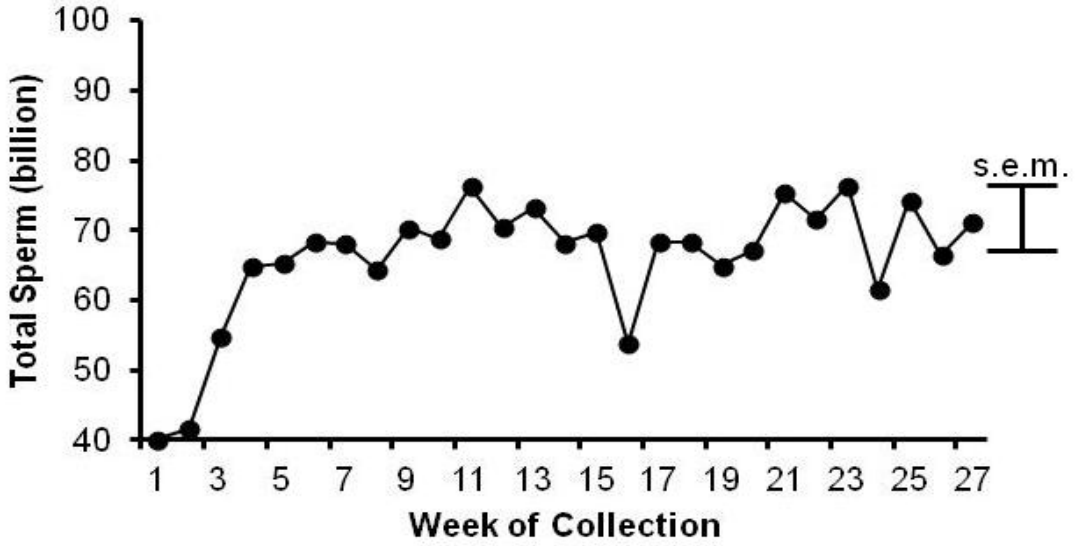

Figure 7. Effect of Week of Collection on Total Sperm. Boars were 27 and 54 weeks of age when the collections began and ended, respectively. Standard error of the mean = 5.6 billion.

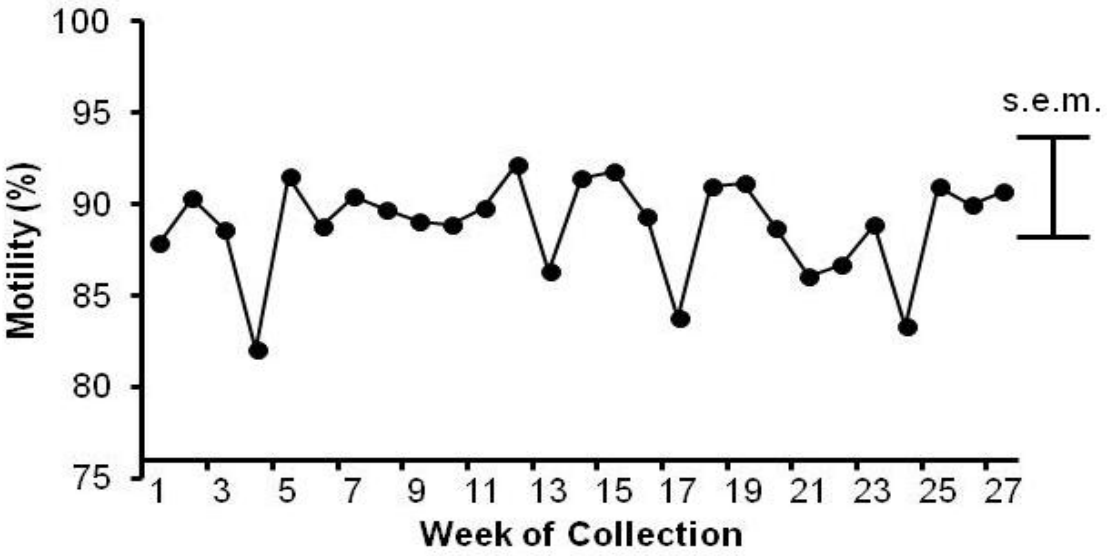

Figure 8. Effect of Week of Collection on Motility. Boars were 27 and 54 weeks of age when the collections began and ended, respectively. Standard error of the mean = 2.3%.

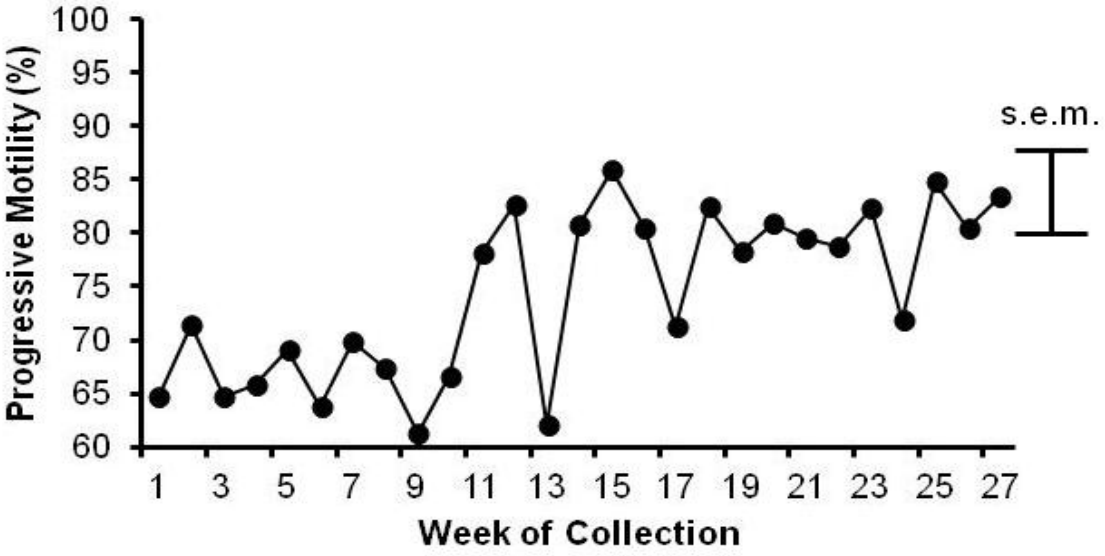

Figure 9. Effect of Week of Collection on Progressive Motility. Boars were 27 and 54 weeks of age when the collections began and ended, respectively. Standard error of the mean = 3.9%.

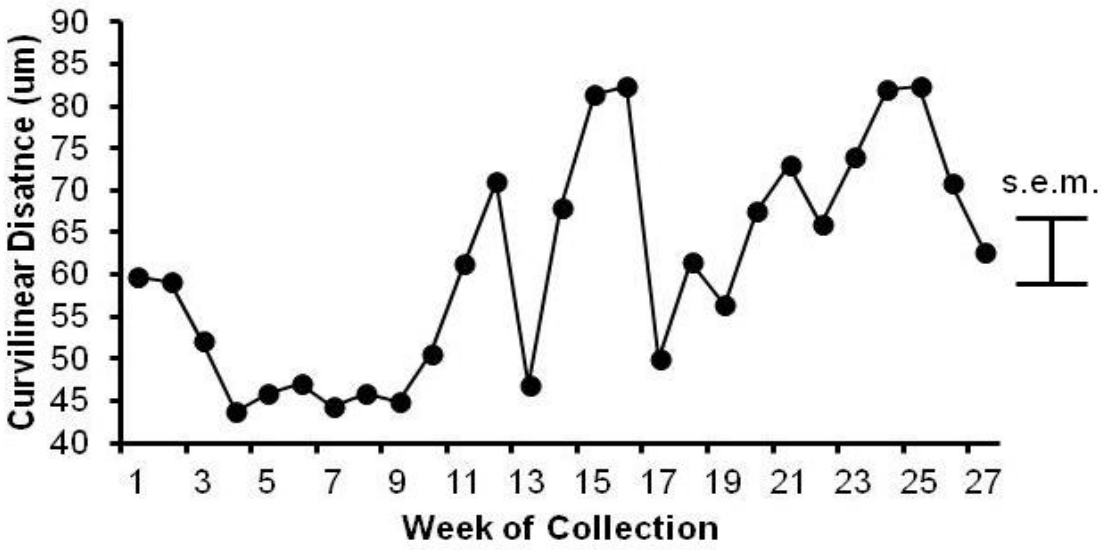

Figure 10. Effect of Week of Collection on Curvilinear Distance. Boars were 27 and 54 weeks of age when the collections began and ended, respectively. Standard error of the mean = 3.5 um.

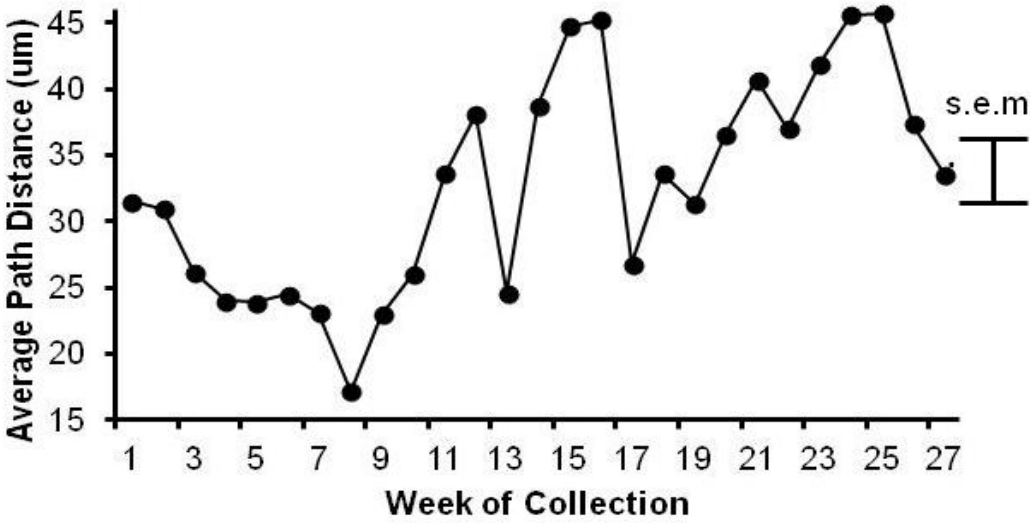

Figure 11. Effect of Week of Collection on Average Path Distance. Boars were 27 and 54 weeks of age when the collections began and ended, respectively. Standard error of the mean = 1.9 um.

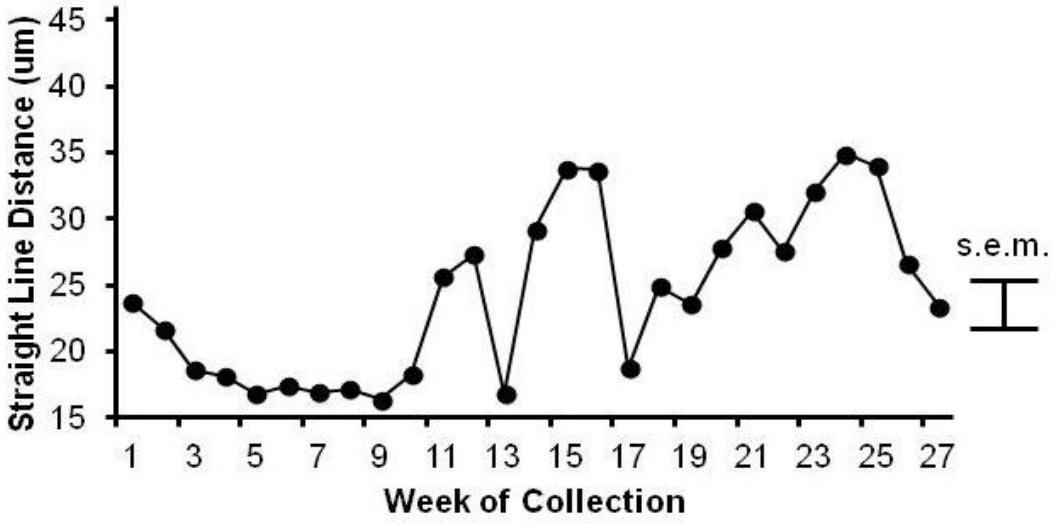

Figure 12. Effect of Week of Collection on Straight Line Distance. Boars were 27 and 54 weeks of age when the collections began and ended, respectively. Standard error of the mean = 1.4 um.

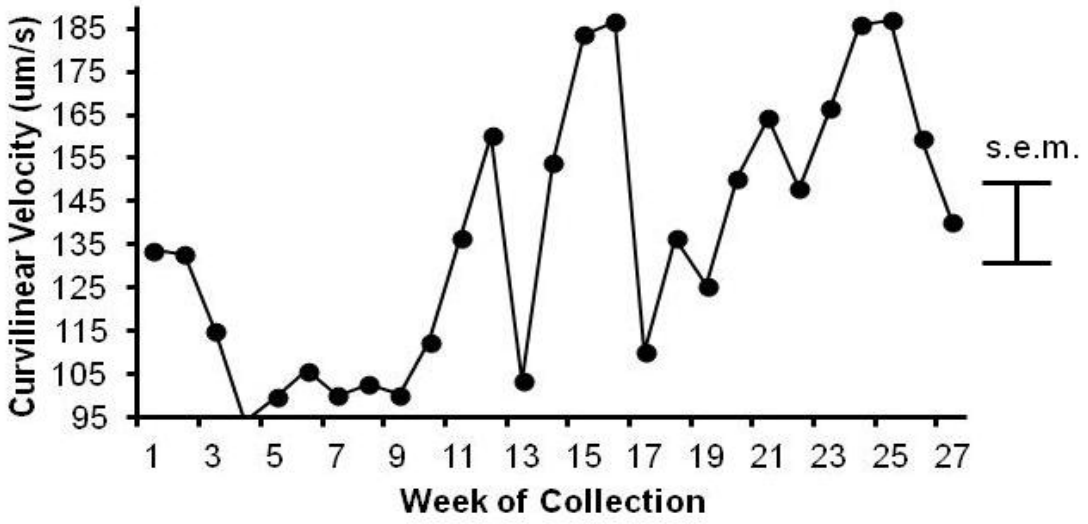

Figure 13. Effect of Week of Collection on Curvilinear Velocity. Boars were 27 and 54 weeks of age when the collections began and ended, respectively. Standard error of the mean = 7.8 um/seconds.

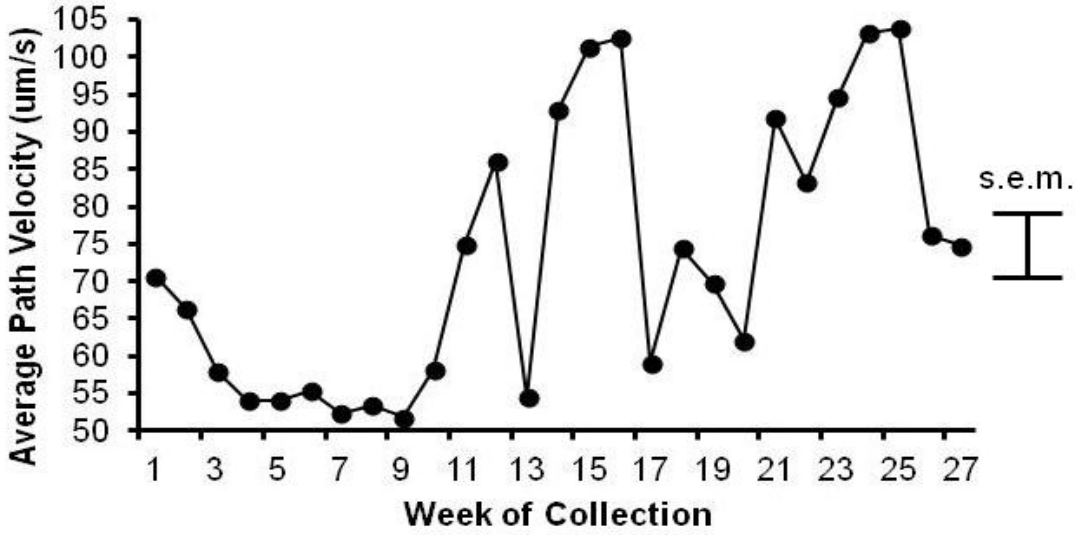

Figure 14. Effect of Week of Collection on Average Path Velocity. Boars were 27 and 54 weeks of age when the collections began and ended, respectively. Standard error of the mean = 4.6 um/seconds.

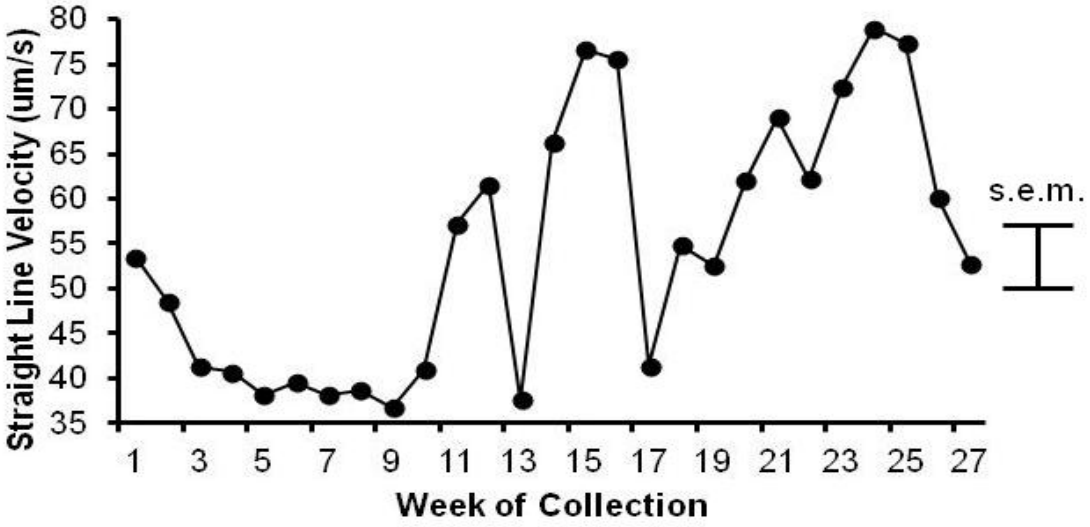

Figure 15. Effect of Week of Collection on Straight Line Velocity. Boars were 27 and 54 weeks of age when the collections began and ended, respectively. Standard error of the mean = 3.5 um/seconds.

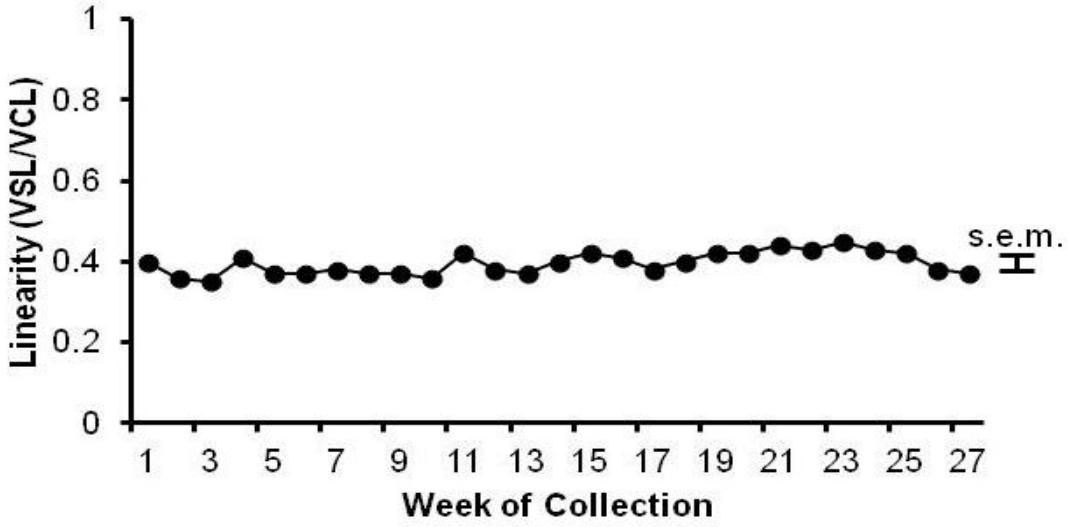

Figure 16. Effect of Week of Collection on Linearity. Boars were 27 and 54 weeks of age when the collections began and ended, respectively. Standard error of the mean = 0.01.

Figure 17. Effect of Week of Collection on Amplitude of Head Displacement. Boars were 27 and 54 weeks of age when the collections began and ended, respectively. Standard error of the mean = 0.21 um.

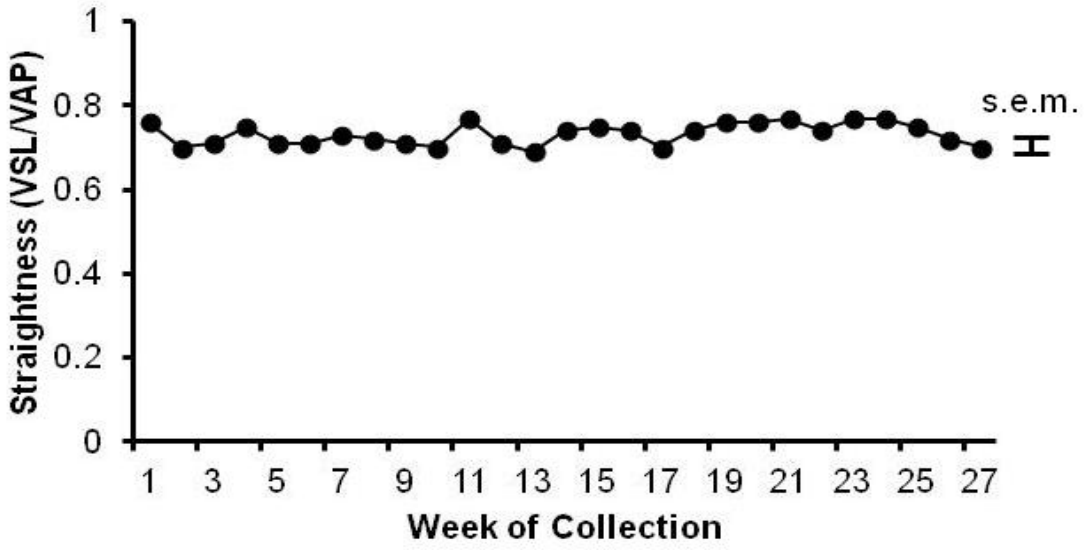

Figure 18. Effect of Week of Collection on Straightness. Boars were 27 and 54 weeks of age when the collections began and ended, respectively. Standard error of the mean = 0.01.

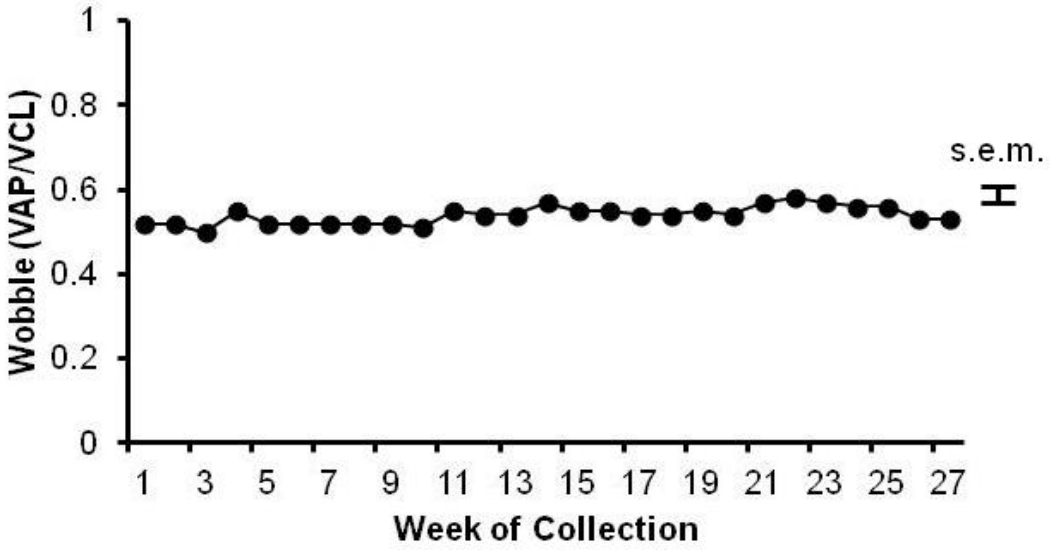

Figure 19. Effect of Week of Collection on Wobble. Boars were 27 and 54 weeks of age when the collections began and ended, respectively. Standard error of the mean = 0.01.

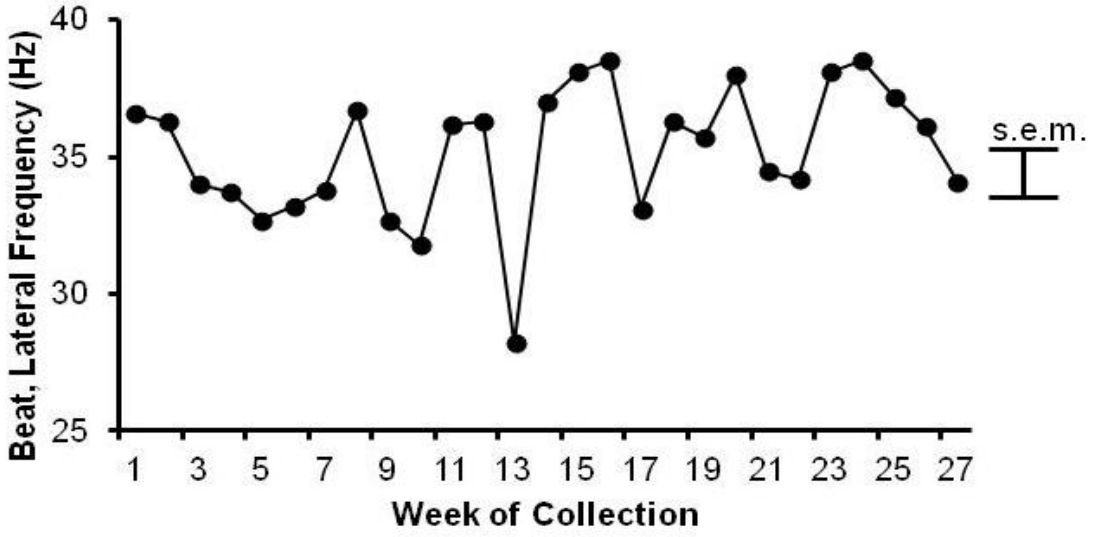

Figure 20. Effect of Week of Collection on Beat, Lateral Frequency. Boars were 27 and 54 weeks of age when the collections began and ended, respectively. Standard error of the mean = 1.1 Hz.

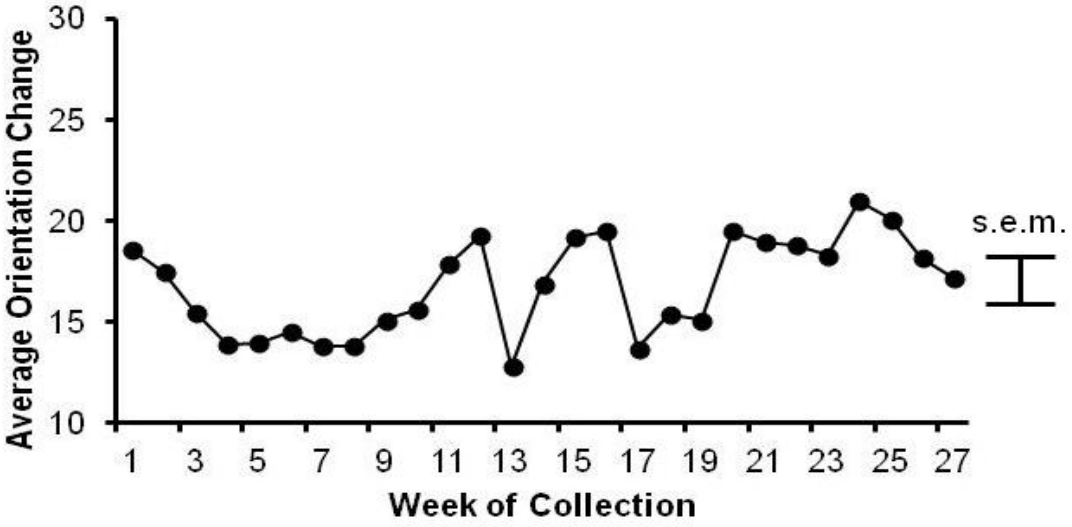

Figure 21. Effect of Week of Collection on Average Orientation Change. Boars were 27 and 54 weeks of age when the collections began and ended, respectively. Standard error of the mean = 0.9.

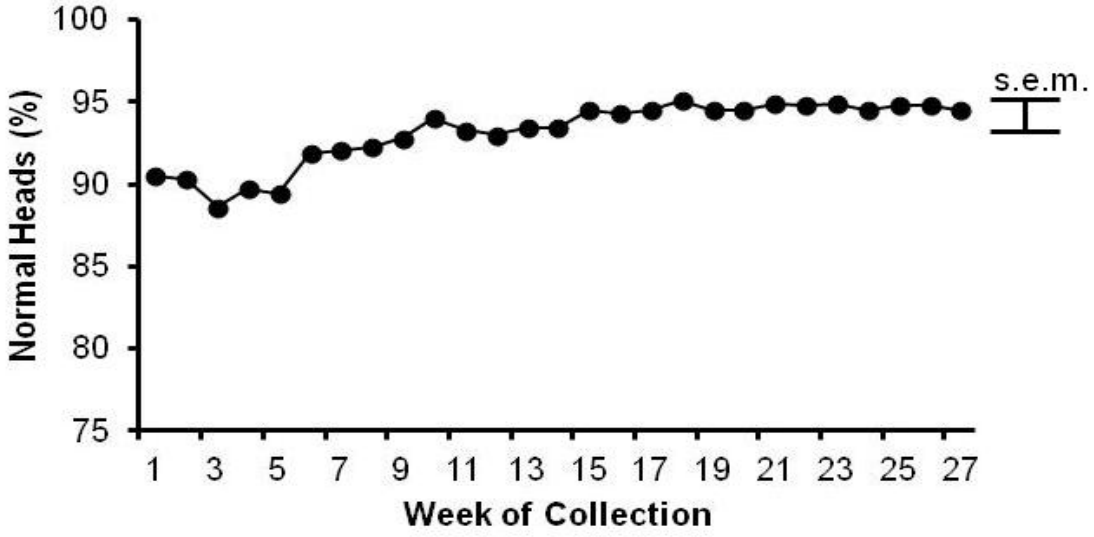

Figure 22. Effect of Week of Collection on Normal Heads. Boars were 27 and 54 weeks of age when the collections began and ended, respectively. Standard error of the mean = 0.5%.

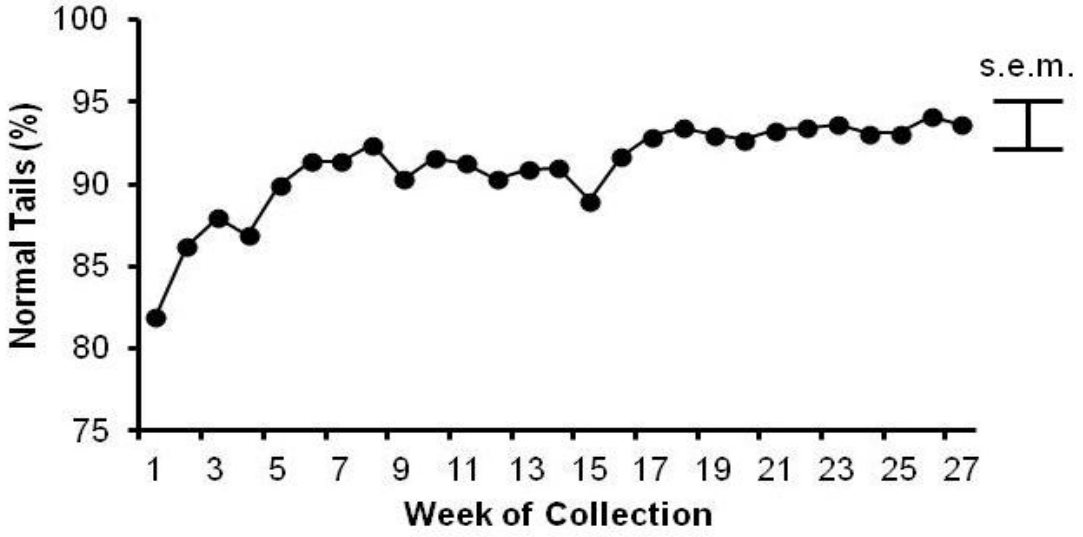

Figure 23. Effect of Week of Collection on Normal Tails. Boars were 27 and 54 weeks of age when the collections began and ended, respectively. Standard error of the mean = 0.8%.

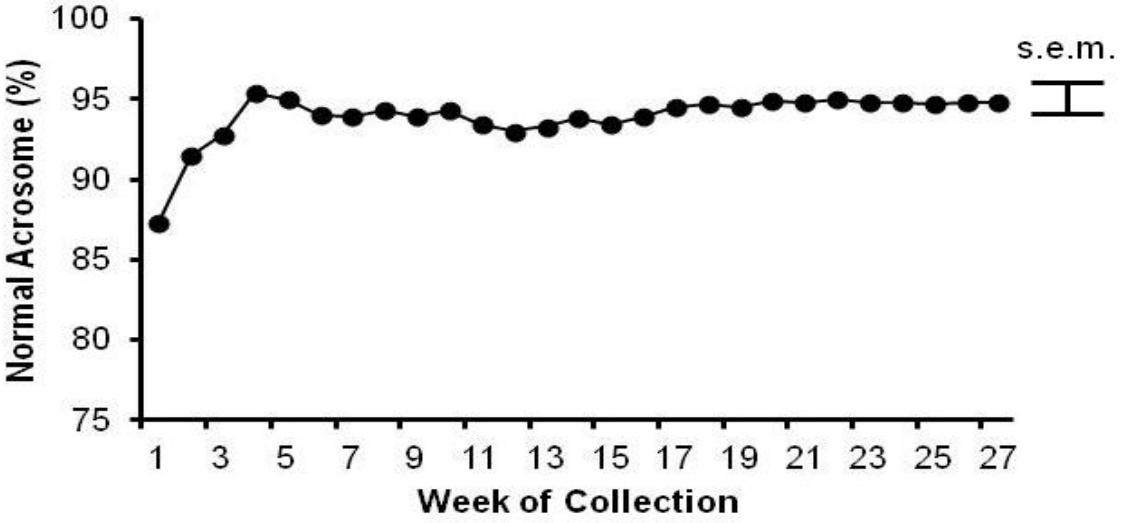

Figure 24. Effect of Week of Collection on Normal Acrosome. Boars were 27 and 54 weeks of age when the collections began and ended, respectively. Standard error of the mean = 0.6 %.

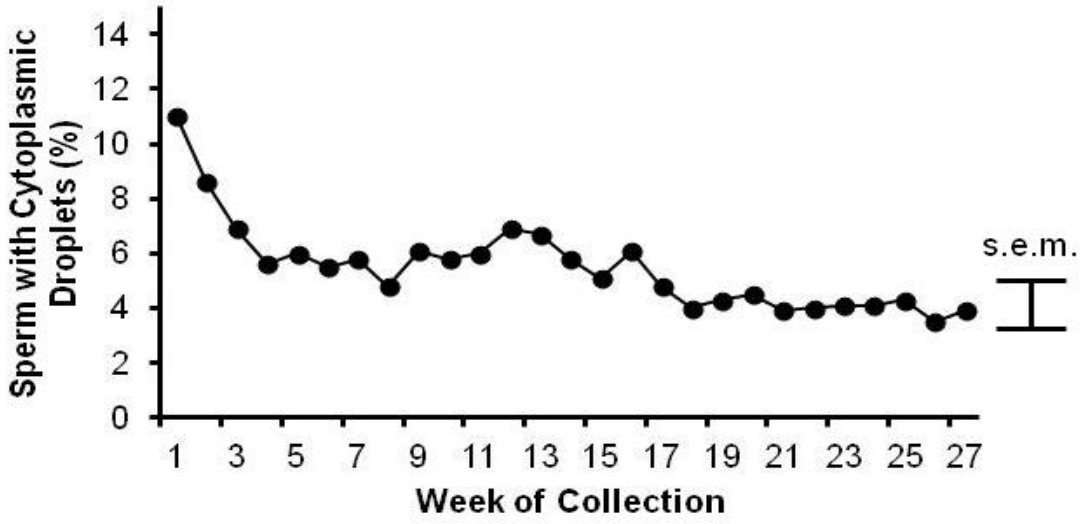

Figure 25. Effect of Week of Collection on Sperm with cytoplasmic droplets. Boars were 27 and 54 weeks of age when the collections began and ended, respectively. Standard error of the mean = 0.6%.